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REVIEW ARTICLE

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Morphological classifications of enteric neurons – 100 years after Dogiel

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Abstract The first differentiation of enteric neurons into three morphological types was done by the russian histologist A. S. Dogiel on the basis of the different shapes and lengths of their dendrites. Although a number of authors considered his results during the following decades, only a division into two types withstood time: type I neurons had one long and several short processes, whereas type II neurons were characterized by several long processes. Some further structural features were discussed but substantial progress was not made until the late 1970s. This stagnation was due to some inaccuracies in Dogiel´s descriptions, to the fact that most histologists in this field followed the reticular concept of the nervous system, to the idea that enteric neurons represent no more than a vegetative, postganglionic relay station between the central nervous system and the periphery, and to methodological difficulties. With the application of modern neuroanatomical techniques it was realized that the enteric nervous system contains a considerable number of neuronal subpopulations. The search for morphological correlates of the chemical diversity of enteric neurons was done mainly in the pig and the guinea-pig. In the pig, additional structural features such as axonal projection, distribution of neurons within ganglia, within different plexuses and along the length of the gut, blood supply etc. were included as criteria for further refining neuronal classification. Most of our knowledge about functional features of enteric neurons, e.g. chemical coding, neuronal connectivity, electrophysiological behaviour, was derived from studies in the guinea-pig small intestine. In light of interspecies differences, comparison of findings from different species is mandatory. The search for morphological and functional peculiarities of human enteric neuronal circuitry has to consider all methodological and conceptual advances made within the past 100 years since the pioneering work of Dogiel.

Key words Enteric nervous system · Morphology · Innervation · Intestine · Neuron

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Introduction

In the late 19th and early 20th century, some fundamental principles of the autonomous gastrointestinal functions were realized (Bayliss and Starling 1899; Trendelenburg 1917). The term "gastroenterology", which was coined by the German physician Hemmeter – one of the founders of an American gastroenterological society in 1897 (Martini 1996), entered general usage (Chen and Chen 1995). Langley (1900, 1921) introduced the name "enteric nervous system" (ENS) to characterize the peculiarity of the neuronal elements within the gut wall. Some years before, based on the works of Ramón y Cajal and formulated by Waldeyer (1891), the neuron doctrine ("Neuronenlehre") was founded in contrast to the reticular concept of the arrangement of the nervous tissue (reviewed Kirsche 1984; Peters et al. 1991; Clarke and O´Malley 1996). The dispute between the proponents of the two rival theories would remarkably influence the recognition of the enteric neuroarchitecture for more than half a century.

Criteria for classifications since Dogiel

In 1899, Dogiel (Fig. 1) published his last work dealing with the histological differentiation of enteric neuron populations. His attempts were the first to suggest a correlation between structural and functional features of enteric neurons. Although he favoured the reticular concept, his classification based on the possibility of distinguishing between neuronal processes as dendrites ("Protoplasmafortsätze") and axons ("Axencylinderfortsätze", "Nervenfortsätze"). As dendrites he regarded processes

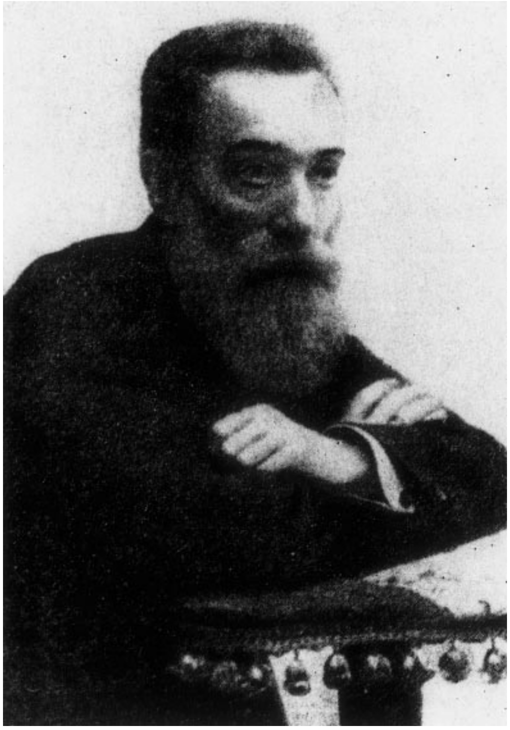


Fig. 1 Aleksandr Stanislavovic Dogiel (1852–1922; from Schierhorn 1981, with permission)

that ramify within the ganglion of origin whereas axons do not (Dogiel 1895b, 1896, 1899), although he reported on dendrites emanating from the axon as well as collaterals of axons (Dogiel 1895a). Dogiel's main criteria for distinguishing different neuron types were the lengths and shapes of dendrites. Furthermore, he mentioned sizes of nerve cell bodies, their locations within ganglia and the positions of nuclei. Very important for his functional conclusions (Table 1) were the observations that in some although rare instances ("einer oder der andere von ihnen"), axons of myenteric type I neurons could be followed into fibres enmeshing bundles of the external musculature and, that dendritic branches of type II neurons could be occasionally traced to the mucosal plexus. Axons of myenteric type III neurons could be followed over considerable distances through other ganglia without leaving the plexus. No functional suggestion about this type was made by Dogiel. However, his concept was that different shapes of somata and dendrites correlate with different functions, one link being the projection of the axon.

The following decades saw less striking progress in this field. This was partly due to some vagueness in Dogiel´s original descriptions concerning the distinctions between the dendritic tree patterns of the three types. Prior to Dogiel, Ramón y Cajal (1893) suggested that enteric neurons have several long processes that cannot be distinguished into axons and dendrites. A number of later authors gave up Dogiel´s distinction between dendrites and axons in type II neurons (La Villa 1898; Ramón y Cajal 1911; Müller E. 1921; van Esveld 1928; Oshima 1929; Harting 1931; Sokolowa 1931; Stöhr 1931; Okamura 1934) whereas others maintained this distinction (Koelliker 1896; Hill 1927; Kolossow and Sabussow 1928; Rossi 1929; Iwanowa 1958). A further dispute arose as to the general possibility and functional significance of a morphological classification of enteric neurons at all. This was denied by researchers until the recent past (Kuntz 1913, 1923; Johnson 1925; Michail and Karamanlidis 1967; Christensen 1988). The most important argument for the proponents of the possibility of a morphological classification became the presence of *several long processes* in type II neurons and of one long and *several short processes* in other neurons. The validity of this distinction was sufficient for many authors (Hill 1927; Tiegs 1927; van Esveld 1928; Oshima 1929; Iwanow 1930; Harting 1931; Lawrentjew 1931;

Table 1 Some important features of the three enteric neuron types as described by Dogiel (1896, 1899)

	Types and numbers of processes	Dendrites	Axonal course	Suggested function
I	4–20 Dendrites 1 Axon	Branch and end within the ganglion of origin Short, thick, flat, with varicosities, lamellar	Through neighbouring ganglia With collaterals Sporadically to the musculature	Motor
II	1–16 Dendrites 1 Axon	Leave ganglion of origin Structural resemblance to axons Ramify into long, thin, smoothly contoured branches Much longer than type I dendrites Some dendritic branches run to the submucosa and mucosa	To other ganglia	Sensor (secretomotor ?)
III	2–10 (and more) Dendrites 1 Axon	Ramify and end within ganglion of origin Longer than type I dendrites Endings of branches: tapering ("dünner und dünner")	Through other ganglia Traceable over considerable distances	?

Kolossow and Sabussow 1932; Reiser 1932; Murat 1933; Cavazzana and Borsetto 1948; de Biscop 1949; Jabonero 1951, 1958, 1960; Stöhr 1949, 1952; Greving 1951b; Temesrékási 1955; Kolossow and Milochin 1963) and resulted in "collapsing of the classifications" (Furness and Costa 1987), which furthermore frequently referred to only two types of neurons. The characteristic flat and lamellar shape of the type I dendrites – "lamellenförmig" (Dogiel 1899; "Dendritenlamellen"; Lawrentjew 1929) became a facultative feature for the differentiation of type I neurons. Based on the shapes and lengths of their short processes, occasional subdivisions of the type I neurons had been proposed, but these merely underlined the general grouping into two types of enteric neurons (Hill 1927; Lawrentjew 1931; Greving 1951a, b; Temesrékási 1955; Jabonero 1958, 1960).

Further reasons for the reduction of Dogiel´s original classification were manifold. Many of the authors cited above were followers of the reticular concept of the nervous system. In an extreme view, the neuronal perikarya were regarded as cytoplasmatic and nucleated junctions of a complicate neural syncytium extending between the central nervous system and the target tissues. Consequently, some authors avoided the terms "dendrite" and "axon" since they would anyhow communicate with each other and described them rather as long and short "processes" (Stöhr 1931; Reiser 1932). Others restricted their results to the "proof" of anastomoses between dendrites of different neurons as demonstrated by drawings (Cole 1930).

In another view, the nerve cells within the gut were regarded as simple postganglionic neurons of sympathetic and parasympathetic preganglionic nerves. Important arguments for this reduction were deduced from the works of E. Müller (1921), Lawrentjew (1929, 1931), Sokolowa (1931) as well as Iljina and Lawrentjew (1932), who reported gradients of the distributions of type I and II neurons along the gastrointestinal tract and related these gradients to the segmental levels of parasympathetic and sympathetic preganglionic neurons, respectively. This was exaggerated by Botár et al. (1942), who moreover denied that structural differences between enteric neurons imply functional differences and that neurons in the gut establish local reflex arches as was suggested by Dogiel. They obviously gave up the concept of the "enteric nervous system" as defined by Langley.

Furthermore, methodological factors influenced the progress in this field. In contrast to Dogiel, most later authors did not use whole-mount specimens, but sections. Some researchers recognized that the classical histological methods used (methylene blue technique, metal impregnations) that stain only subsets of neurons, may not demonstrate equivalent neuron populations in different species (Ottaviani 1940). The suggestion was made that unstained neurons may be functionally different from stained neurons (Schofield 1962).

Nevertheless, some new aspects were introduced during the decades between Dogiel and the 1970s. L.R. Müller (1912) distinguished two myenteric neuron types based on the topographical vicinity of their processes to the musculature. Besides Langley (1900) and in contrast to Dogiel, he was one of the first to suggest that ganglion cells in the gut are quite different from other autonomic neurons. He already recognized the absence of pericellular sheaths around enteric neurons, a feature that has been confirmed more recently by fine structural studies. Kuntz (1913, 1923) described terminations of nerve fibres ("synapses") on enteric neurons, thus favouring the neuron theory. Iwanow (1930) found axons of type I neurons to be oriented in one direction and Temesrékási (1955) estimated lengths of axonal projections within the different ganglionated plexuses. Ito (1936) as well as Ito and Nagahiro (1937) differentiated three classes of neurons based on their size, and found that the excentricity of nuclei is a frequent non-pathological feature of enteric nerve cells. Small neurons were observed that did not belong to the types of Dogiel (Stöhr 1949, 1952; Gunn 1959, 1968), whereas Fehér and Vajda (1972) distinguished three types purely on the basis of cell-soma size. Based on their staining intensity, enteric neurons were classified by Honjin et al. (1959), Michail and Karamanlidis (1967) and Sutherland (1967) into argentophobe and argentophile neurons. Schofield (1962) considered the number of processes to be relevant for functional properties, not their lengths and shapes.

In the late 1970s, the development of new techniques, first of all immunohistochemistry, led to a dramatic increase of our knowledge of the diversity of enteric neurons (Furness et al. 1991). However, important reviews of that period neither mentioned any light-microscopical classification of enteric neurons (Furness and Costa 1980), nor did they refer to Dogiel´s types (Gershon and Erde 1981).

In the 1980s, Stach (1980, 1981, 1982a, b, 1985, 1989) introduced a morphological classification in the pig small intestinal ENS. He took advantage of the eclectic nature of silver impregnation. This allows the undisturbed observation of some of the neurons with their completely stained processes since a number of other neurons – glia cells and surrounding tissues – remain scarcely or not at all represented. The directions of axonal projections, which have direct functional relevance, are thus traceable over considerable distances whereas axonal terminals remain unstained in most cases. For this purpose, intracellular dye injection techniques are more suitable (Bornstein et al. 1991). This classification is far from being finished: the definition of further criteria to distinguish, e.g., different subpopulations of type III neurons, is the focus of ongoing work. The six types hitherto described make up at least 20% of the whole myenteric population (Brehmer and Stach 1998). It uses all structural features that can be observed in silver-impregnated whole mounts: dendritic architecture, direction of axonal projection, location of cell bodies within ganglia, within the different ganglionated plexuses and along the length of the small intestine, and position of the nucleus. Some of these features had been considered already by earlier investigators but had almost never been incorporated into a consistent concept. Furthermore, the old and inappropriate term “multipolar” was replaced by “multiaxonal” (for type II neurons) and “multidendritic, uniaxonal” (for the other classes of neurons possessing one axon). In this classification, a strong correlation between dendritic architecture and axonal projection in the three neuron types of Dogiel is emphasized (I, oral; II, circumferential and vertical; III, aboral). Stach (1982b) was compelled to introduce a fourth type when he observed neurons with a characteristic dendritic tree pattern combined with an exclusively vertical axonal projection. Combinations of silver impregnation with a vascular injection technique revealed a specific blood supply of some morphologically characterized neuron populations – those division still based on the reduced classification into two neuron types (Stach 1977, 1979). The preferentially vascularized “type I/2” neurons (Stach 1979) were later recognized as being type III neurons (Stach 1982a).

At the same time, numerous attempts were made to demonstrate the shapes of enteric neurons simultaneously with their chemical and/or electrophysiological features (Hodgkiss and Lees 1980, 1983; Costa et al. 1982; Furness et al. 1983, 1985; Bornstein et al. 1984; Kobayashi et al. 1984; 1985; Erde et al. 1985; Katayama et al. 1986). The realization that in the ENS there exists a great variety of chemically coded neuron types (reviewed in Furness and Costa 1980; Llewellyn-Smith et al. 1983; Furness and Costa 1987) triggered the search for morphological correlates of the distinct neurochemical types, particularly in the guinea-pig. Furness et al. (1988a) used an intracellular dye injection technique for the demonstration of cellular morphology. A correlation between dendritic architecture and axonal projection could not be established due to incomplete filling of most of the longer processes. Thus, their criteria for describing four types of neurons remained restricted to shapes and lengths of (short) processes and to soma sizes. All these studies yielded excellent and important findings extending our knowledge about functional properties of single enteric neurons and the ENS as a whole but did not result in a more appropriate morphological classification.

Conventional ultrastructural studies revealed different types of synaptic vesicles in enteric neurons (Baumgarten et al. 1970; Gabella 1972; Wilson et al. 1981a, b) and up to nine different neuron types according to fine structural criteria (Cook and Burnstock 1976), but it was hardly possible to reconcile them with any of the cell types recognized by light microscopy.

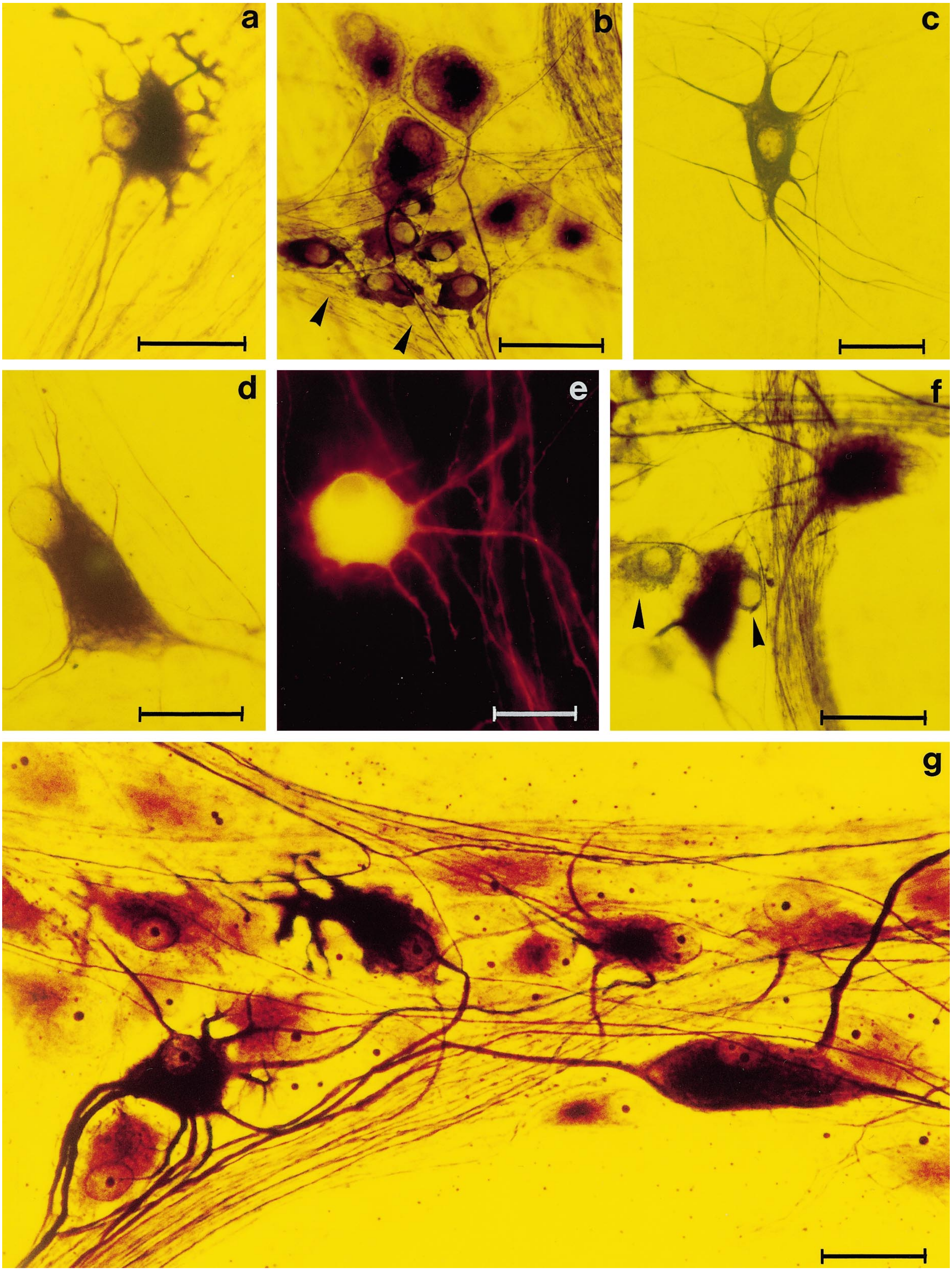
Neuron types

In the following section enteric neuron types will be described from a morphological point of view as they are discussed in the recent literature. Since most advance was made in type II neurons, we will start with this type. Figure 2 (a-d, g) displays the neuron types I to IV as seen in silver impregnated material. A further characterization using a tracing technique (Fig. 2e) and a combination of silver impregnation with a histochemical reaction (Fig. 2f) led to the unequivocal distinction of type IV neurons of Stach in contrast to types I to III of Dogiel. Thus, the need for an extended classification beyond Dogiels concept is illustrated.

Dogiel type II (Fig. 2b, g)

The most striking advance to correlate structural and functional features of enteric neurons was achieved in type II neurons. Regardless of interspecies differences and different methodological approaches, the disagreement between researchers may be the lowest in this type. These neurons have smoothly contoured outlines and several long processes that can be regarded structurally (Stach 1981: “multiaxonal”) and functionally (Hendricks et al. 1990; Bornstein et al. 1994) as axons. Type II cells occur in two forms, an adendritic and a dendritic form (Stach 1981, 1989; Furness et al. 1988a, 1990; Bornstein et al. 1991). The adendritic form has similar projection patterns in pig, guinea-pig and, probably, rat small intestinal myenteric plexus: one axon extends typically into the mucosa whereas others run circumferentially within secondary strands of the myenteric plexus (Stach 1981; Furness et al. 1990; Mann et al. 1997; Brehmer et al. 1999). The myenteric dendritic type II neurons have, in the guinea-pig small intestine, long aboral projections (Brookes et al. 1995). In this species and in contrast to uniaxonal neurons, a majority of type II neurons shows the electrophysiological after-hyperpolarization (AH) phenomenon following their action potentials (Hirst et al. 1974; Hodgkiss and Lees 1983; Bornstein et al. 1984; Erde et al. 1985; Katayama et al. 1986; Iyer et al. 1988; Tamura 1992, 1997; Clerc et al. 1998). However, in human and pig, this phenomenon seems to be not as widely present as in the guinea-pig (Brookes et al. 1987; Cornelissen et al. 1996). Using immunohistochemistry, a number of peptides have been shown within these neurons (Scheuermann et al. 1987; Furness et al. 1988b; Bornstein et al. 1989; Timmermans et al. 1989, 1992a; Song et al. 1991; 1994; Neunlist and Schemann 1997). Calbindin (in guinea-pig) and calcitonin gene-related peptide (in pig) were used as markers in ultrastructural studies of myenteric type II neurons (Pompolo and Fur-

Fig. 2a–c Silver-impregnated, myenteric neuron types I, II, III from pig small intestine, whose shapes correspond most closely to the original descriptions given by Dogiel. In **b** 6 small NADPHdiaphorase-positive neurons are visible that are not silverimpregnated (*blue-stained*, *arrowheads*). **a**, **c** Silverimpregnation. **b** NADPH diaphorase reaction and subsequent silver impregnation. **d**–**f** Myenteric Stach type IV neurons. **d** Silverimpregnation, **e** post mortem DiI-tracing from a single mucosal villus, **f** NADPHdiaphorase reaction and subsequent silver impregnation (*arrowheads* NADPHdiaphorase-stained neurons). **g** Myenteric ganglion from pig jejunum with four strongly impregnated (*black-brown stained*) neurons; from left to right: type III, I, IV, II. (Silver impregnation). *Bars* 50 µm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ness 1988; Scheuermann et al. 1991). These neurons are cholinergic in the guinea-pig (Li and Furness 1998) and, throughout all species investigated, non-nitrergic (Costa et al. 1992b, 1996; Ward et al. 1992; Aimi et al. 1993; Furness et al. 1994; Timmermans et al. 1994 a, b; Brehmer and Stach 1997). Calbindin-immunoreactive terminals, arising exclusively from type II cells, can be detected forming synapses on calbindin-positive nerve-cell bodies in guinea-pig myenteric plexus (Pompolo and Furness 1988; Furness et al. 1990). Based on work in this species, type II neurons are regarded as intrinsic primary afferent neurons (Kunze et al. 1995; Furness et al. 1998) that establish self-reinforcing networks. In an alternative view, they represent enteric interneurons (Wood 1994).

Dogiel type I (Fig. 2a, g)

Besides classical histological methods (see above), these multidendritic uniaxonal neurons were frequently diagnosed using more modern techniques, including histochemistry, immunohistochemistry, dye injection and tracing methods. Recently, their original structural feature, the shapes of the endings of the short processes (“lamellar”, “flat”, “stubby”, “club-shaped”) became a more obligatory criterium. Attempts to reconstruct three-dimensionally the typical lamellar dendrites of myenteric type I neurons of the guinea-pig were undertaken by Pompolo and Furness (1990) based on thin sections, as well as by Hanani et al. (1998) and Meedeniya et al. (1998) using confocal microscopy. In the pig small intestine, the occurrence of silver-impregnated type I neurons is restricted to the myenteric plexus. Here, they are located mainly in the oral parts of ganglia and the great majority (about 85%) projects orally in the plane of the plexus (Stach 1980). These neurons are, in the pig small intestine, non-nitrergic (Brehmer and Stach 1997) whereas in other species (guinea-pig, rat, dog, human) nitrergic type I neurons were identified (Costa et al. 1992b; Ward et al. 1992; Young et al. 1992, 1995; Bogers et al. 1994; Cracco and Filogamo 1994; Furness et al. 1994). At present, and in contrast to the type II neurons, it is impossible to assign a common functional role to them in the guinea-pig. A number of functional classes of neurons are regarded to be of Dogiel type I-morphology in this species: orally and aborally projecting interneurons, inhibitory and excitatory motorneurons for circular and longitudinal musculature (Brookes and Costa 1990; Pompolo and Furness 1990; Brookes et al. 1991, 1992, 1997; Steele et al. 1991; Costa et al. 1992a; Wattchow et al. 1995; Young and Furness 1995; Young et al. 1995; Portbury et al. 1996; Song et al. 1996; Clerc et al. 1998). This may be due to the existence of subtypes bearing the common morphological feature of a characteristic dendritic shape. On the other hand, the demonstration of dendritic architecture depends extremely on methodology. The nicotinamide-adenine-dinucleotide-phosphate-diaphorase (NADPHd) reaction used as a marker for nitrergic neurons may serve as an example. NADPHd-positive neurons were classified as Dogiel type I (Aimi et al. 1993; Cracco and Filogamo 1994). However, caution is recommended when classifying neuron types based on this histochemical reaction which may represent dendritic shapes incompletely (Brehmer and Stach 1997).

Dogiel type III (Fig. 2c, g)

These most common “multipolar” enteric neurons have, after Dogiel´s (1899) description, dendrites that branch and end within the ganglion of origin (in contrast to the processes of type II neurons he classified as dendrites). They become thinner towards their endings (“tapering”). Morphologically, in the pig small intestine, Stach (1982a) separated them clearly from type I neurons because of striking differences in dendritic tree pattern (long-dendritic, tapering) and main axonal projections (about 85% aborally). However, there seem to exist subpopulations in this species that can be distinguished by their axonal projections and/or their chemistry, e.g. nitrergic and non-nitrergic ones (Timmermans et al. 1992b, 1993; Brehmer and Stach 1997), but not yet by their dendritic tree patterns. At least some type III neurons in the pig small intestine may be regarded as intrinsic or intestinofugal interneurons (Timmermans et al. 1992b, 1993). In the guinea-pig small intestine, besides submucosal nerve cells (Bornstein et al. 1986), myenteric neurons projecting to the mucosa were classified as type III (Furness et al. 1985). Based on the drawings provided and on later descriptions (Portbury et al. 1995), neither the submucosal nor the myenteric cells correspond to Dogiel´s original delineation of type III neurons. Their dendrites are scarcely longer than those of type I neurons, and Dogiel did not describe short dendritic myenteric neurons projecting vertically. The guinea-pig myenteric type III neurons (Furness et al. 1985) more closely resemble pig myenteric type IV neurons (Stach 1982b), which also project to the mucosa (Brehmer et al. 1999). In the guinea-pig small intestine, a novel class of neurons was termed filamentous neurons.

Filamentous neurons

These have “numerous relatively short (usually less than 50 µm), tapering, and sometimes branching processes, and their single long process” (Furness et al. 1988a). They can be found also in guinea-pig large intestine (Messenger et al. 1994) and are regarded as descending interneurons (Portbury et al. 1995; Clerc et al. 1998).

Type IV neurons (Fig. 2 d-g)

These are found in the pig small intestine and have short, scarcely branched dendrites emanating asymmetrically from the soma. Typically, their nucleus is eccentrically placed within the cell body (Stach 1982b). Using morphometry, it could be shown that the peculiar dendritic tree pattern of type IV neurons is clearly separable from that of, at first glance structurally similar, single type V neurons (Brehmer and Beleites 1996). Type IV neurons are non-nitrergic (Brehmer and Stach 1997), they project from the myenteric plexus to the mucosa (Brehmer et al. 1999) and may represent secretomotor neurons. External submucosal type IV neurons project similarly vertically but mainly to the myenteric plexus (Stach 1983; Brehmer et al. 1998).

Type V neurons

These make up a characteristic non-nitrergic population within myenteric and external submucosal ganglia mainly in the pig lower small intestine (Stach 1985, 1989; Brehmer and Stach 1997; 1998; Brehmer et al. 1998). They appear as single cells or as very conspicuous aggregates. Within the latter, the compact clustering of dendrites suggests the possibility of a simultaneous activation of different type V neurons. In the myenteric plexus, these neurons project mainly aborally whereas the course of external submucosal type V axons is not known.

Type VI neurons

These are found in the pig small intestine (Stach 1989) and are present in myenteric as well as external submucosal ganglia and display a nitrergic phenotype (Timmermans et al. 1994b; Brehmer and Stach 1997). Their frequency along the small intestine is highest in the ileum (Brehmer and Stach 1998). The morphological hallmark of type VI neurons are dendrites arising from the axon hillock and the proximal axon (“axonal dendrites”). The myenteric type VI neurons project mainly aborally within the plane of the plexus whereas the submucosal type VI neurons project frequently vertically, crossing circular muscle bundles and running into the myenteric plexus (Stach 1983; Brehmer et al. 1998).

Small neurons (Fig. 2 b, f)

Besides larger neuron types that can be distinguished from each other more or less clearly by shape criteria, there seem to exist many smaller neurons that may differ in function from the larger ones in guinea-pig and pig. They were named “small neurons with few processes” (Furness et al. 1988a), “minineurons” (Stach 1989) or “simple neurons” (Messenger et al. 1994) and are probably functionally heterogeneous. As compared with the filamentous neurons of guinea-pig myenteric plexus (see above), significantly smaller neurons with filamentous dendrites send their axons to the tertiary component of the myenteric plexus and to the circular musculature. They are regarded as longitudinal and circular muscle motor neurons (Clerc et al. 1998). Others, e.g. in the pig internal submucosal plexus, may represent mucosal effector neurons (Timmermans et al. 1997; Brehmer et al. 1999).

From morphé to morphology

From the above examples, it is obvious in guinea-pig and pig that significant species differences are an important factor impeding a thorough understanding of the ENS. To remedy this, consistent criteria for a morphological classification may be helpful. Besides guinea-pig and pig, there exists a considerable amount of data about neurochemical diversity and axonal projections of enteric neurons in the rat (Sundler et al. 1993) although information on a morphological classification in this species is scarcely available (Browning and Lees 1994). Some authors observed neurons even in other species (opossum, Christensen 1988; guinea-pig, Lees et al. 1992, Nichols et al. 1992; horse, Pearson 1994) resembling Stach type IV or VI neurons in the pig. Since these authors did not use all the criteria for identification that were applied by Stach, it is not clear whether these neurons are equivalent to the respective neuron types in the pig small intestine. Otherwise, the discrepancy in naming structurally similar neuron populations as type IV in the pig (Stach 1982b) and type III in the guinea-pig (Furness et al. 1985) indicates the possibility of a further divergence of the currently used morphological nomenclature of enteric neurons.

The diversity of chemically defined and functionally differing subtypes of enteric neurons established in guinea-pig, rat and pig (Furness and Costa 1987; Sundler et al. 1993; Costa et al. 1996; Timmermans et al. 1997) and the attempts to transfer concepts from these species to the human gut require a sound basis of categorizing enteric neurons. Recently, human enteric neurons were morphologically described and classified using different methods (Timmermans et al. 1994a; Wattchow et al. 1995, 1997; Porter et al. 1996; Krammer et al. 1998). Besides the variety of modern methods, silver impregnation should hold its place as an efficient technique for an accurate representation of the shapes of large numbers of neurons simultaneously within a single specimen. Even in brain research, there is a “definite renaissance” (Jones 1984) of silver-impregnation techniques for, e.g. the classification of cortical neurons. That the shape of a neuron “provides the key to its role in the nervous system” (Peters et al. 1991) may be true also for the ENS. The classification scheme proposed by Stach (1989) offers criteria surpassing pure description of shapes (from morphé ...), thus achieving a more valuable framework for categorization of typical and significant rather than individual and variable structural features (... to morphology). It is our belief that this classification represents an important step to bridging the gap between the basic morphological types of Dogiel and the multiplicity of neurochemical and functional types recognized today.

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