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Ependyma of the central canal of the rat spinal cord: a light and transmission electron microscopic study

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INTRODUCTION

Comparatively little information is available on the subject of repair and replacement of ependymal epithelium during the postnatal period in mammalian forms (for review see Bruni, Del Bigio & Clattenburg, 1985). Available data, however, suggest that lesions of ventricular ependyma in adult animals, with few exceptions (Altman, 1963; Betty, 1977; Bruni, Clattenburg & Paterson, 1983; Pilkington & Lantos, 1979), are generally irreversible and there is a lack of regenerative capacity in postnatal animals including man (Fleischhauer, 1972; Garfia, Mestres & Rascher, 1980; Hakansson & von Mecklenburg, 1981; Heinzmann, Marquart & Kriegel, 1978). Although proliferative activity is a feature of ependyma during embryonic and early postnatal development (Altman & Bayer, 1978; Das, 1979; Korr, 1980; Rakic & Sidman, 1968), it persists only minimally into adulthood (Altman, 1963; Adrian & Walker, 1962; Chauhan & Lewis, 1979; Gilmore, 1971; Korr, 1980; Rakic & Sidman, 1968; Smart, 1961). In contrast to the cerebral ventricles, however, proliferation of ependymal cells appears to be more common in response to spinal cord injury (Adrian & Walker, 1962; Gilmore & Leiting, 1979, 1980; Matthews, St. Onge & Faciene, 1978, 1979; Wallace, Tator & Lewis, 1983). Bruni & Anderson (1987) recently compared the response to injury of ependymal cells in the central canal of the rat spinal cord with that of cells at a higher level of the neuraxis. The results suggested that proliferation of ependyma in the central canal, unlike the response in the fourth ventricle, is a significant reactive event triggered by localised injury to the cord.

Attempts to further elucidate factors responsible for this difference revealed the need for a detailed study of the lining of the rat central canal along its rostrocaudal length. The objective of this study, therefore, was to identify regional features of the ependyma and features distinguishing them from their counterparts elsewhere in the ventricular system. Some previously published descriptions of the central canal have been provided by Seitz, Lohler & Schwendemann (1981) in the mouse; Rascher, Booz, Nacimiento & Donauer (1985) in the cat and Gilmore, Sims & Leiting (1984) and Kohno (1969) in rats. In addition, the embryonic and postnatal development of ependyma in the central canal of the mouse has been examined by Sturrock (1981) and Rafols & Goshgarian (1985) recently centred their study on tanycytes in the cervical cord of young rats.

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MATERIALS AND METHODS

Four adult male Sprague–Dawley rats (200–250 g body weight) were used in this investigation. They were untreated and maintained under controlled conditions in accordance with the guidelines for care and use of laboratory animals established by the Canadian Council on Animal Care. They were anaesthetised by an intramuscular injection (0·23 ml/100 g) of ketamine (90 mg/kg), and xylazine (10 mg/kg) and were then perfused transcardially with 2% paraformaldehyde and 2·5% glutaraldehyde in 0·12M phosphate buffer. A laminectomy was carried out and, with the cord *in situ*, representative blocks of tissue from each of the cervical, thoracic, lumbar and sacral segments as well as the filum terminale were excised. Under a dissecting microscope, the cord was cut at C7, T13 and L6 vertebral levels using the first and last ribs and the sacroiliac joint as reference points. The caudalmost segment of the cord was then divided at the point of maximum taper into blocks designated sacral, conus and filum. Tissue blocks were then further fixed by immersion in a fresh volume of the same fixative for 12–24 hours at 4 °C. They were subsequently postfixed in 2% phosphate-buffered osmium tetroxide, stained *en bloc* with 2% uranyl acetate, dehydrated in graded alcohols and embedded in Epon 812. Ultrathin sections were stained with lead citrate and viewed with a Philips 201 TEM.

Semithin (0·5 μm) plastic sections of tissue cut serially in the transverse plane and stained with 1% methylene blue-azure II were used for orientation and sampling. Sections from the spinal cord segments of one animal were examined serially at 25 μm intervals under a light microscope using an oil immersion objective ($\times 100$) and the number of ependymal cells lining the central canal was determined. Only cells with visible nuclei were counted.

RESULTS

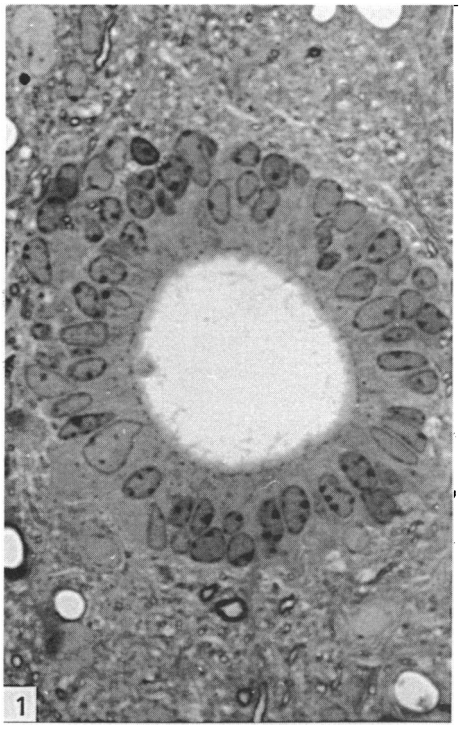
In the rat cervical cord, the central canal was typically round or oval in shape, patent (Fig. 1) and eccentrically placed in the central grey matter such that the grey commissure was always narrower dorsally than ventrally. From thoracolumbar levels of the cord to the conus medullaris, however, the central canal was usually collapsed and assumed a characteristic dorsoventrally elongated shape (Fig. 2). Unlike other levels, the central canal of the filum terminale was the most variable in shape and occupied the largest cross sectional area of the cord (Fig. 3).

Fig. 1. Central canal of the cervical cord showing its typical round or oval shape in transverse section. The walls consisted for the most part of uniformly arranged pseudostratified columnar cells; some of which had basal processes (see Fig. 4). $\times 750$.

Fig. 2. Unlike cervical and upper thoracic levels, the central canal was dorsoventrally elongated in shape and often collapsed at sacral levels. Note the presence of a vacuolated zone (arrow) in the ventral midline immediately beneath the central canal (see Fig. 10). $\times 720$.

Fig. 3. The central canal in the filum terminale was distinguished by its large size and irregular shape. It was lined by a single layer of distinctly ciliated cuboidal ependymal cells many of which extended processes to the external glial laminae. $\times 620$.

Fig. 4. Columnar ependymal cells from the ventral midline region of the central canal (*cc*) in the thoracic cord. The cells were characterised by large basally located nuclei. Ependymal cells bordered directly upon neurons (*N*) and their processes (*) within the subjacent neuropil. Processes (arrow) projecting radially into the neuropil were occasionally seen to arise from the basal pole of some ependymal cells bordering on the central canal. $\times 6100$.



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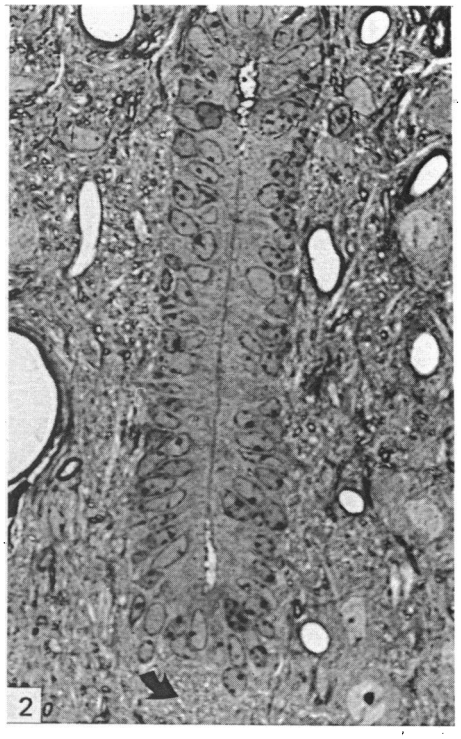

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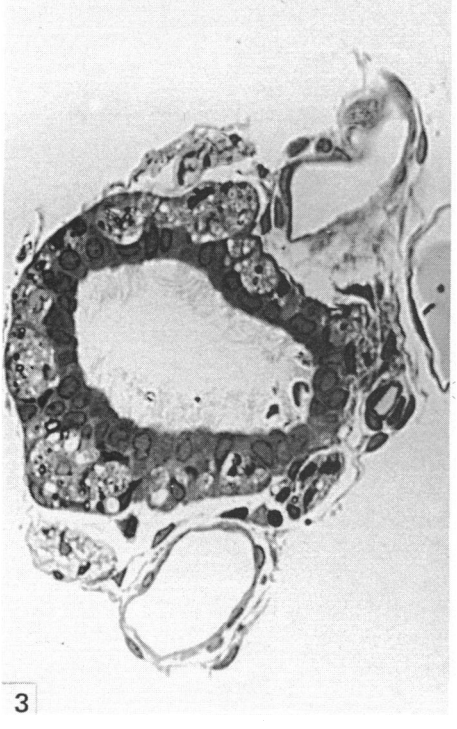

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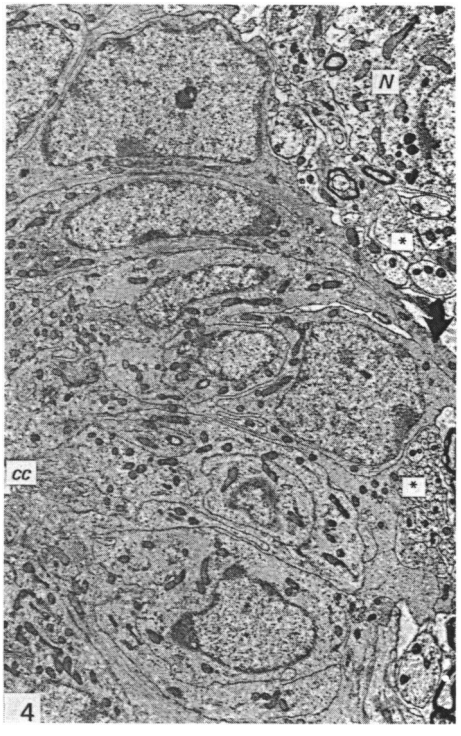

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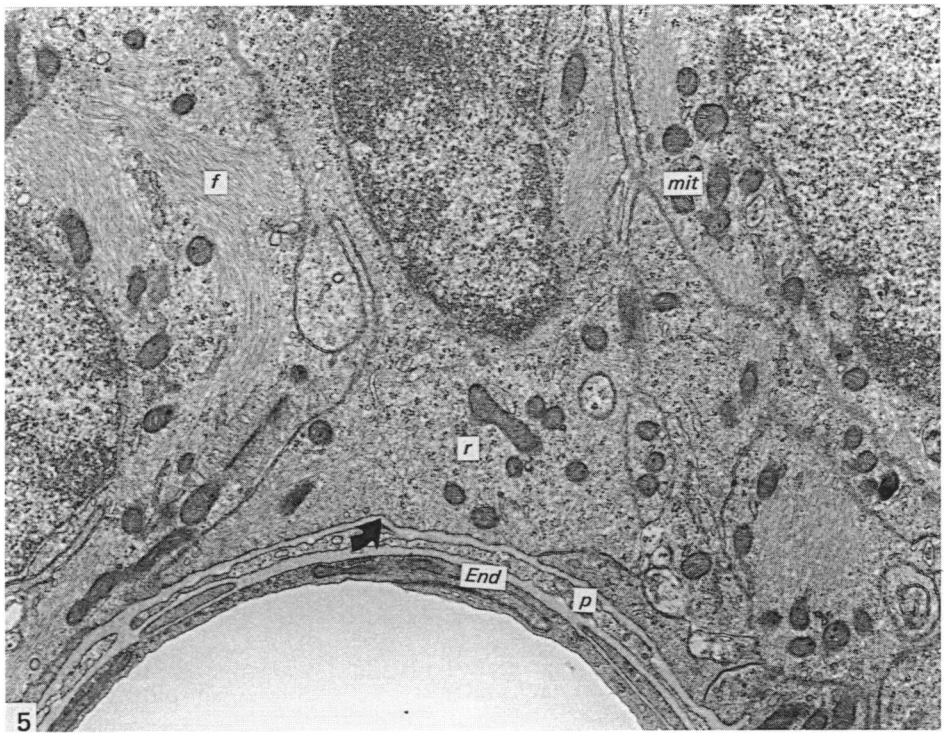

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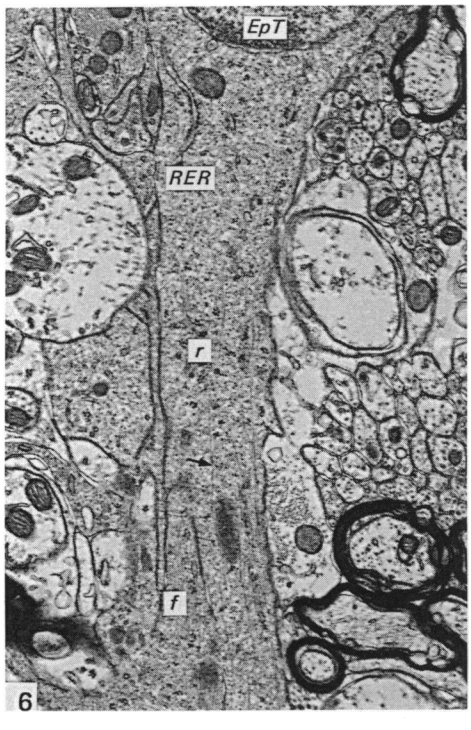

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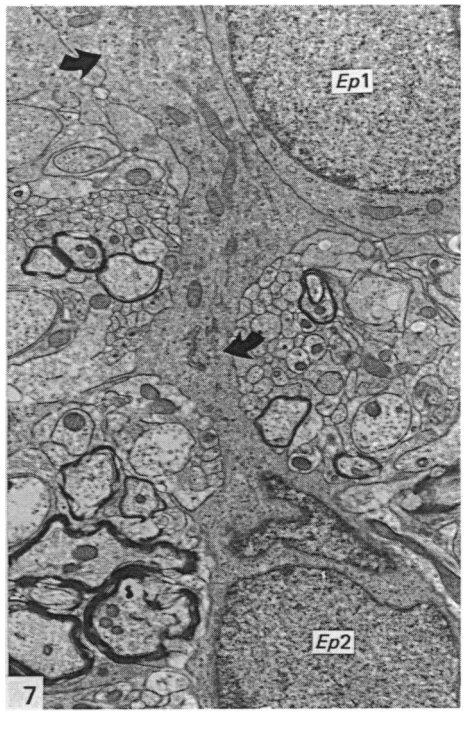

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The central grey matter typically broadened in the thoracic cord and continued to do so in the caudal direction so that the central canal appeared to be displaced ventrally and the dorsal grey commissure was wider than the ventral grey commissure. This was most conspicuous in the sacral cord and the conus medullaris. As a consequence the number of neuronal cell bodies located immediately dorsal and lateral to the central canal increased along the caudal gradient. Neurons around the central canal have been shown to project to areas of the medullary and pontine reticular formation and are driven by noxious mechanical and thermal stimuli (Nahin, Madsen & Giesler, 1983). Myelinated axons were sparse in the region surrounding the central canal except ventrally where they often invaded the grey commissure (Fig. 1). Blood vessels, in contrast, were numerous in the vicinity of the central canal, often in close proximity to the otherwise avascular ependymal lining (Fig. 2).

The lining of the central canal consisted for the most part of a single layer of pseudostratified cuboidal to columnar ependymal cells with large mid to basally located nuclei (Figs. 1–3). In some locations, however, the lining was up to 4 cell layers thick. In this circumstance, the more peripherally located cells were smaller, polygonal in shape and contained condensed cytoplasm and nucleoplasm. Ependymal cells, for the most part, were arranged uniformly and inserted radially around the lumen of the central canal. Those cells in the dorsal and ventral midline regions, however, were often elongated with closely spaced nuclei. In some floor and roof plate regions nuclei were often lacking and pale staining cytoplasm sometimes extended into the midline raphe.

The lumen of the central canal at thoracic levels of the cord was lined by significantly fewer ependymal cells ($37 \pm 0{\cdot}6$, $\overline{X} \pm$ S.E.M.) than at any other level. In keeping with its relatively larger size, however, the central canal in the conus medullaris ($57 \pm 0{\cdot}9$), sacral ($59 \pm 0{\cdot}8$) and lumbar ($52 \pm 0{\cdot}7$) cord was lined by a significantly larger number of cells than at cervical level ($41 \pm 0{\cdot}5$) or in the filum terminale ($40 \pm 1{\cdot}7$).

At the ultrastructural level, ependymal cells of the central canal typically had round, slightly oval or elongated nuclei that occupied a large part of the cell (Fig. 4). Chromatin was homogeneous except for condensations along the nuclear membrane. Most ependymal cells terminated abruptly on the subjacent neuropil (Fig. 4) with some abutting directly on the abluminal basal lamina of the perivascular space of capillaries (Fig. 5). A prominent process occasionally extended radially from the basal pole of some cells; most often in the dorsal and ventral midline regions of the

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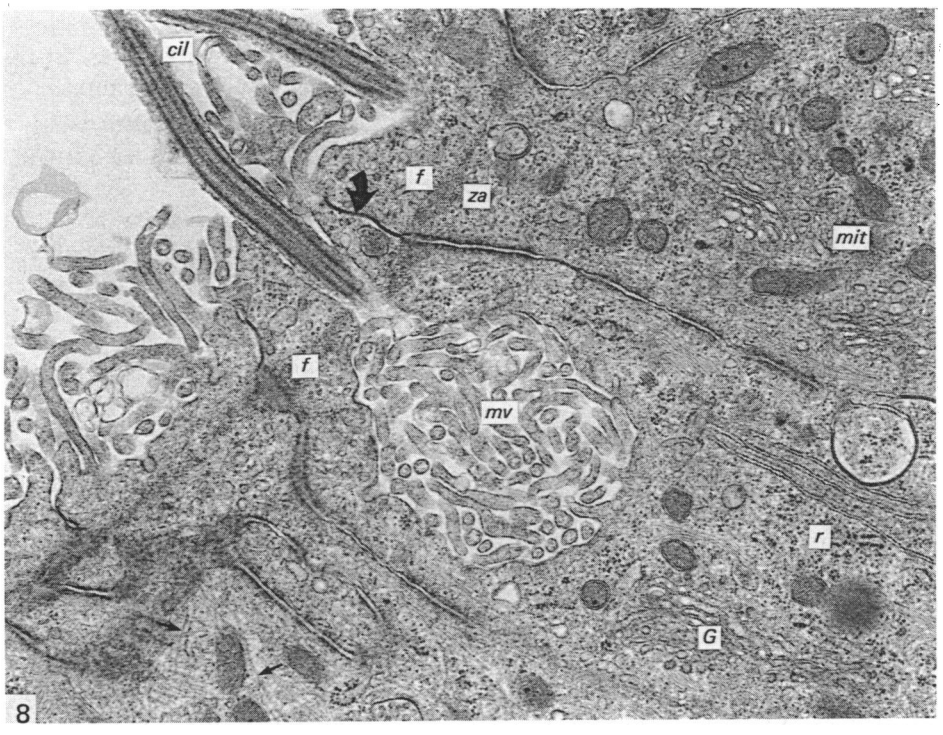
Fig. 5. Basal poles of ependymal cells lining the central canal shown terminating directly upon the abluminal basal lamina (arrow) of the pericapillary space. Unlike the apical region of the cell, the basal cytoplasm contains only a few organelles; mitochondria (*mit*), free ribosomes (*r*) and filaments (*f*). *End*, endothelium; *P*, pericyte cytoplasm. × 13100.

Fig. 6. Enlargement of the proximal segment of a tanycyte (*EpT*) process showing its content of organelles; mitochondria, a few ribosomes (*r*), a few profiles of rough endoplasmic reticulum (*RER*), numerous tubular and vesicular profiles of smooth endoplasmic reticulum, a few microtubules (arrow) and numerous intermediate filaments (*f*). Neurons and their axons and dendrites surround these processes and are partially separated from them by thin astrocytic lamellae. × 13150.

Fig. 7. A cell variant (*Ep2*) with the characteristics of an ependymal cell but located below the lining of the central canal. Note the apical process (arrows) which extends between ependymal cells (*Ep1*) to reach the lumen of the central canal. × 6100.



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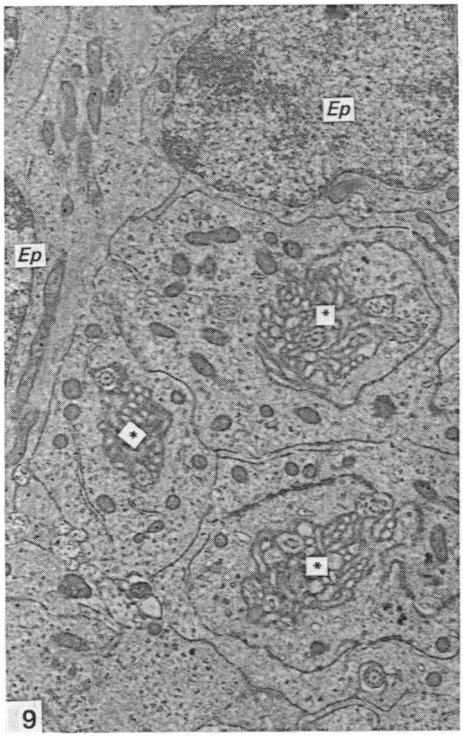

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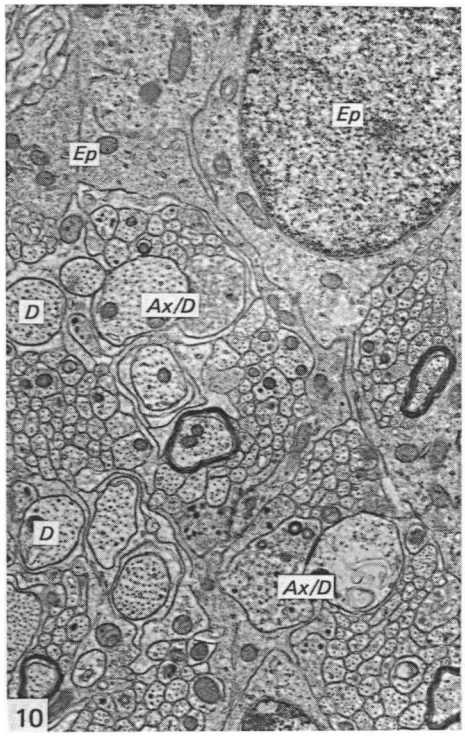

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central canal (Fig. 6). These tanycyte ependymal cells were encountered along the length of the central canal with a frequency of about 1–3 cells per section in the cervical to sacral cord and 2–5 in the conus medullaris and filum terminale. Their basal processes contained many mitochondria, a few polyribosomes, profiles of smooth endoplasmic reticulum and numerous intermediate filaments (Fig. 6). Tanycytic processes often contacted neurons and terminated on blood vessels subjacent to the central canal. An additional ependymal cell variant infrequently encountered was displaced from the lining and extended an apical process between ependymal cells to reach the lumen of the central canal (Fig. 7). Similar cells with condensed cytoplasm and chromatin and lacking processes were also encountered in clusters of 3–6 cells in the dorsal and, particularly, the ventral midline regions above and below the central canal. They were most common in the caudal part of the cord, particularly in the sacral segments and were reminiscent of the radiation-sensitive cell clusters in early postnatal rats which Gilmore *et al.* (1984) reported to be of astroglial lineage.

Organelles were displaced apically within the cytoplasm of ependymal cells (Figs. 4, 8) and included abundant filaments, numerous mitochondria, a few segments of granular endoplasmic reticulum, a prominent Golgi complex, scattered ribosomes, a few microtubules and many vesicular and tubular profiles of smooth endoplasmic reticulum (Fig. 8). The lateral border between adjoining ependymal cells was generally not extensively interdigitated. Profiles of dendrites and unmyelinated axons were often wedged between the lateral aspects of adjoining ependymal cells and were free at their luminal surface. The most prominent feature of the cells was a well developed terminal bar complex in the apical region. It consisted of a series of zonulae adherentes with filamentous material inserted onto their dense cytoplasmic surfaces (Fig. 8). Gap junctions were also encountered as part of the complex nearest the luminal surface, between zonulae adherentes apically and, infrequently, along the basolateral surface of the cells.

Above the terminal bar region, irregular masses of cytoplasm frequently bulged from the apex of individual cells into the central canal and contacted one another when the lumen was collapsed. Elsewhere the lumen of the central canal was occasionally filled with proteinaceous material resembling the ground substance of ependymal cells suggesting extrusion into the central canal and a lack of CSF flow. Along the

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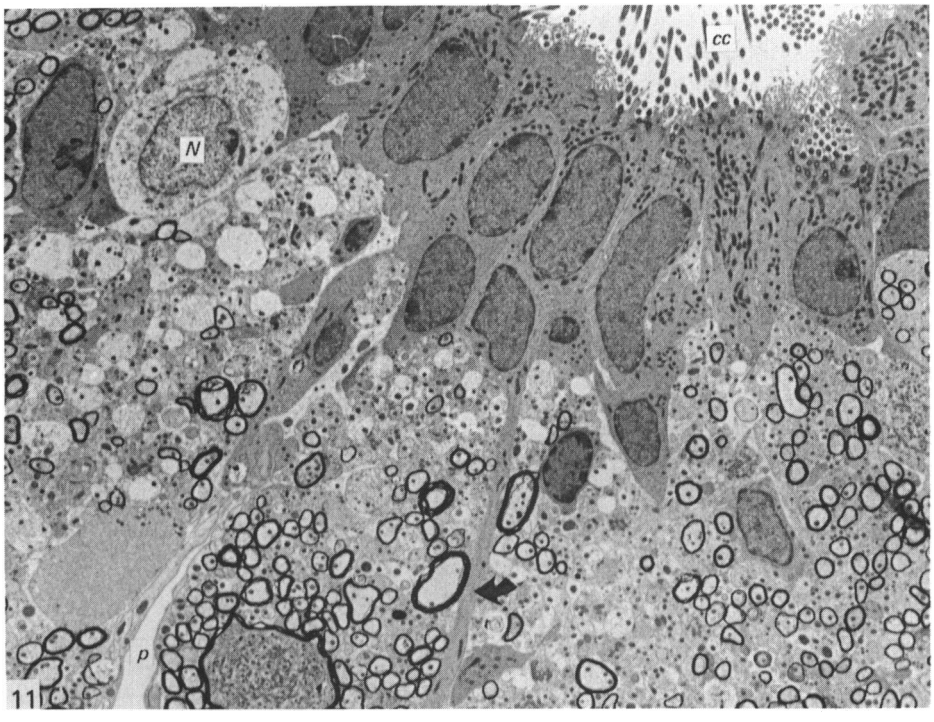
Fig. 8. The apical cytoplasm of ependymal cells typically contain an abundance of filaments (*f*), numerous mitochondria (*mit*), a few segments of granular endoplasmic reticulum, a prominent Golgi complex (*G*), scattered ribosomes (*r*), a few microtubules (arrows), and many vesicular and tubular profiles of smooth endoplasmic reticulum. Specialisations of the apical surface include microvilli (*mv*) and cilia (*cil*). Junctional complexes and associated cytoplasmic filaments are prominent features of the lateral boundaries of the cells near their luminal surface. Large arrow, gap junction; *za*, zonula adherens. × 24 500.

Fig. 9. Islands of ependymal cytoplasm (*) in the thoracic cord viewed tangentially to the cell surface and at right angles to the plane of section. They are enclosed by a plasma membrane punctuated by junctional complexes. Although located some distance from the lumen of the central canal, microvilli and cilia nevertheless emerge from their apical cytoplasm. *Ep*, ependymal cell lining. × 18 500.

Fig. 10. Ventral midline region of the central canal in the lumbar cord showing the zone immediately beneath the ependymal lining (*Ep*) as in Fig. 2. The 'vacuolated' appearance of the area is attributable to the presence of many parallel groups of neurites in a glomerulus-like arrangement. Ependymal processes occasionally separate and partially surround these longitudinally coursing neurites. *D*, dendrites; *Ax/D*, axodendritic synapses. × 6000.



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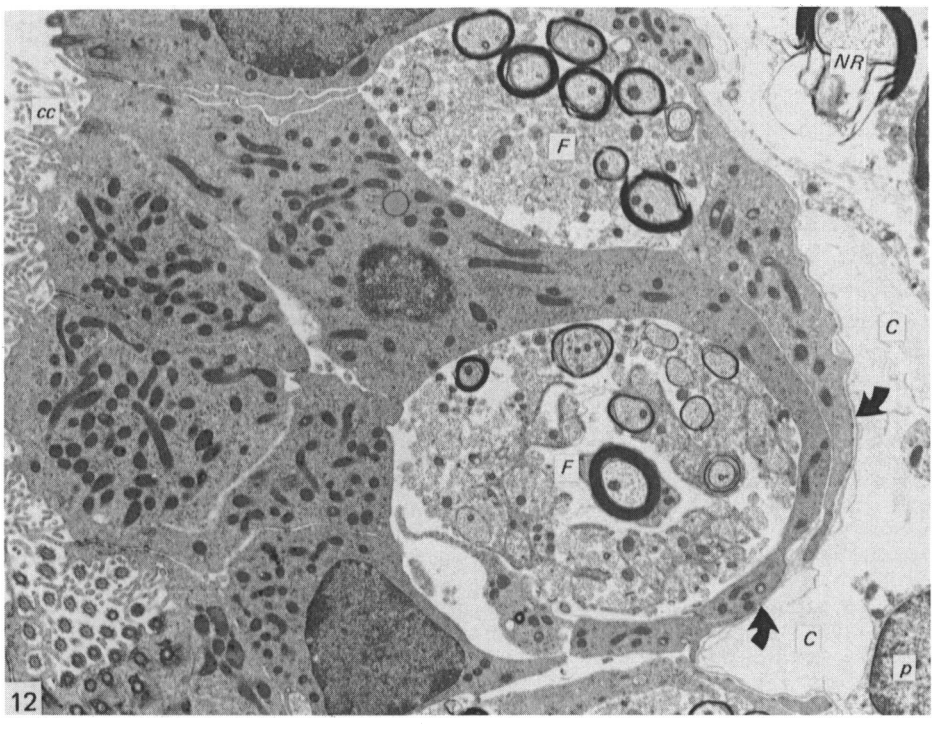

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length of the canal specialisations of the luminal surface of the cells typically included varying numbers of cilia and a profusion of coarse stout microvilli. Cilia sometimes arose from microvillus-filled moats within the apical cytoplasm of some cells (Fig. 8). From the thoracic cord to the filum terminale cilia and microvilli were occasionally seen to emanate from ependymal cells situated some distance from the lumen (Fig. 9). This unusual anatomical arrangement may be indicative of radially directed channels arising from the main canal.

At lumbar and sacral levels of the cord prominent vacuolated areas of grey matter were located in the midline immediately dorsal and ventral to the central canal (Fig. 2). Ultrastructurally, the regions consisted of parallel groups of transversely sectioned axons, mainly unmyelinated, interspersed with dendrites (Fig. 10). In some cases they were partially insinuated among, and surrounded by, ependymal cell processes. Many of the fine diameter axons and dendrites that ramify in the vicinity of the central canal are autonomic visceral afferents (Morgan, Nadelhaft & De Groat, 1981; Neuhuber, 1982). Sympathetic afferents have been located in a groove filled with bundles of longitudinally running dendrites and axons connected by synapses, corresponding precisely to the area located ventral to the ependyma of the central canal as described above (Neuhuber, 1982). A tract of fibres which ran as a tight rostrocaudal bundle in this same location, also in the rat, has been shown to contain a high concentration of Substance P (Gibson, Polak, Bloom & Wall, 1981).

The filum terminale differed most markedly from other segments of the cord (Fig. 3). Its sparse neuropil contained glial cells, many axons and only a few neurons. Prominent amongst the glia was the single layer of flattened ependyma which lined the large irregular canal and contributed to the formation of both the internal and external glial limiting membrane (Figs. 11, 12). Radially directed basal processes arose from many of these cells and extended in a distinctive manner to the pial surface. Along their course, they formed septa which separated fasciculi of longitudinally coursing axons (Fig. 11). Axons without interposed astrocytic laminae often contacted these tanycytic processes which were lined by a prominent basal lamina at the pial surface (Fig. 12). Although the ultrastructure of these cells was not unlike that already described at other levels of the cord, mitochondria were more highly concentrated in their cytoplasm and the terminal bar complex was not conspicuous (Figs. 11, 12). Also, at the luminal surface of the cells cilia were more obvious within the large lumen of the filum than at other levels of the cord. They were long and projected in distinct clusters from the surface of individual cells (Fig. 3).

At cervical, thoracic and lumbar levels of the cord dendrites that come into contact with the cerebrospinal fluid were inserted between ependymal cells lining the

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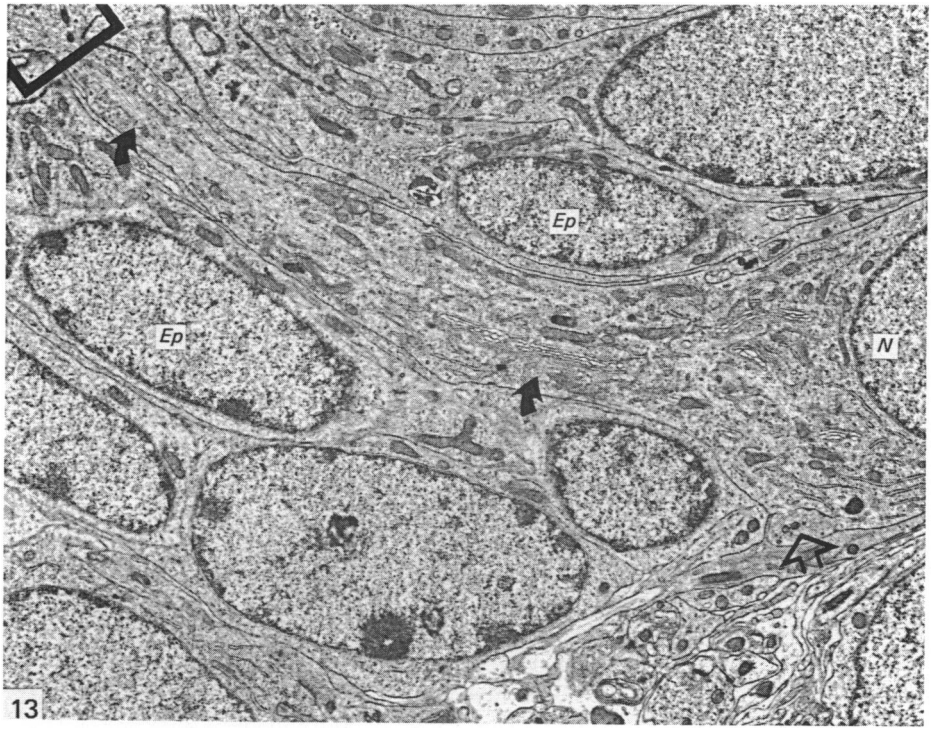
Fig. 11. Survey micrograph of the filum terminale showing a single layer of cuboidal ependymal cells lining the central canal (*cc*). Note that some cells (arrow) span the thickness of the cord and terminate at the pial surface (*p*). They form septae which enclose neurons (*N*) and fascicles of longitudinally coursing axons. × 2700.

Fig. 12. Higher magnification of an ependymal cell in the filum which extends from the lumen of the central canal (*cc*) to the pial surface. The cell forms the external glial limiting membrane by terminating directly on the basal lamina (arrows) at the pial surface. Enclosed within adjoining ependymal processes without intervening glial laminae are fascicles of longitudinally coursing neurites (*F*). *p*, pial cell; *C*, collagen fibrils; *NR*, nerve root. × 5800.



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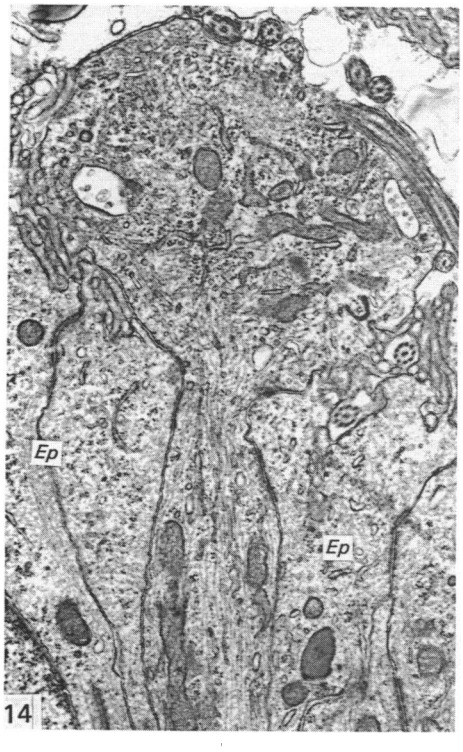

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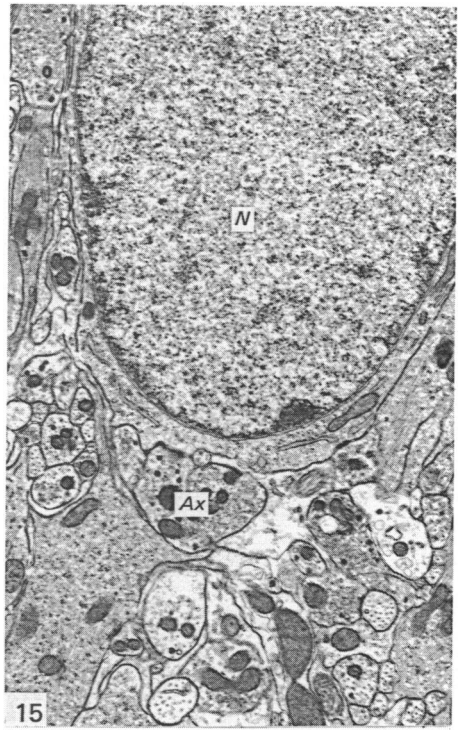

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central canal (Fig. 13). Although infrequent, these slender processes originated from cells located deep to the ependyma but that were distinctly different from ependyma. The dendritic processes terminated within the central canal in an enlargement that displayed numerous mitochondria, microtubules, and abundant vesicular and tubular profiles of smooth endoplasmic reticulum (Fig. 14). The constricted base of the expanded terminals was frequently anchored to adjoining ependymal cells by prominent zonulae adherentes. The neuronal perikarya of origin sometimes were seen to receive axosomatic synapses containing both granular and clear vesicles (Figs. 13, 15).

DISCUSSION

The results of this study reveal that the ependyma lining the rat central canal was similar in ultrastructural appearance and orientation along the length of the cord and not unlike that described in other vertebrate species (Anderson & Waxman, 1983; Rascher *et al.* 1985; Seitz *et al.* 1981; Zamora, 1978; Kriebel, 1981). While resembling its counterpart in the cerebral ventricle it did exhibit some unique features. Notable among these was the prominent complex of intercellular junctions and associated filaments along the lateral border of the cells near their apex. Cross striated filaments in the apical cytoplasm of ependymal cells in the rat cervical and upper thoracic cord, also recognised as being unique with respect to the ventricles, were believed by Kohno (1969) to serve as a support protecting the lumen of the central canal from compression produced by flexion of the vertebral column. Our observations are also in agreement with those of Seitz *et al.* (1981), namely that in the mammalian central canal, cell junctions at the ependymal surface consist of zonulae adherentes and gap junctions. In the cat, however, the lateral borders of dorsal midline ependymal cells contain a few short desmosome-like contacts in addition to occasional gap junctions, whereas the greatly interdigitated ventral midline cells contain a long series of such contacts (Rascher *et al.* 1985). These junctional complexes make plausible the reported dilatation of the central canal that occurs in mammals in response to increased cerebrospinal fluid pressure and the suggestion that the canal may serve as an alternate route for CSF reabsorption (Becker, Wilson & Watson, 1972; Torvik & Murthy, 1977). In contrast, the luminal border of the central canal in lower vertebrates (teleosts and urodeles) is provided with tight junctions that seal the border and preclude exchange between the canal and the intercellular compartment (Zamora & Thiesson, 1980; Anderson & Waxman, 1983; Sandri, Akert & Bennett, 1978). The presence of such tight junctions has prompted the suggestion that the ependymal cells themselves may profoundly modify the

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Fig. 13. Subependymal neuron (*N*) in the lumbar cord extending a dendrite (solid arrows) between ependymal cells (*Ep*) to reach the lumen of the central canal (open rectangle). Open arrow, axosomatic synapse. × 5900.

Fig. 14. Region of the dendritic process enclosed in the open rectangle in Fig. 13 shown terminating within the central canal. Note that the terminal enlargement contains numerous mitochondria, abundant vesicular and tubular profiles of smooth reticulum and polyribosomes. A few microtubules and some rough endoplasmic reticulum are also present. The constricted base of the large round terminal is anchored to adjoining ependymal cells (*Ep*) by prominent zonulae adherentes. × 11950

Fig. 15. Base of the subependymal neuron (*N*) in Fig. 13 showing the presence of an axosomatic synapse (*Ax*). × 9170.

composition of the cerebrospinal fluid by secretory or transporting processes (Zamora & Thiesson, 1980).

Kohno (1969) has also suggested that in the rat, cervical and upper thoracic cord ependymal cells are unique with respect to the ventricles in the sparse distribution of cilia at their surface. Rascher *et al.* (1985) recently reported that unlike the cat, rat canal ependymal cells bear only 1–2 cilia per cell and that there are no bundles of cilia below the first cervical segment. Our observations indicate that in the rat, cilia and a profusion of microvilli arise from the luminal surface of cells along the entire length of the canal. The former are most discernible, however, within the expanded lumen of the filum terminale.

Two ependymal cell variants were identified on the basis of the presence or absence of a radially directed cytoplasmic process originating from the base of the cell. The tanycytic form of ependymal cell was present along the entire length of the central canal in the rat but was found with increased frequency in caudal segments, particularly in the filum. Tanycytes in the central canal, however, regardless of location, appeared to differ from those in the ventricles by the abundance of intermediate filaments they contain. Tanycytes are also present along the length of the central canal in the mouse but are arranged in clusters at the poles of the canal in cervical, thoracic and lumbar segments (Seitz *et al.* 1981). In the cervical cord of young rats, tanycytes are also located deep to the ependyma but retain contact with the lumen of the canal (Rafols & Goshgarian, 1985). Tanycyte processes extend into the midline along the posterior median septum, the ventral white commissure and the grey matter surrounding the canal and terminate in most cases in association with blood vessels (Rafols & Goshgarian, 1985). This anatomical relationship led these investigators to suggest that these specialised cells may modify the composition of substances moving between the perivascular and extracellular spaces. In the caudal central canal of the mouse, however, they are believed to serve as a framework preventing collapse of the canal (Seitz *et al.* 1981).

The filum terminale is noted to be an anomalous structure in various species (Bradbury & Lathem, 1965; Stoltenburg-Didinger & Bienentreu, 1981). In the rat, the central canal of the filum differed significantly from more rostral segments of the cord. It consisted of a large tube comparable in size to that at thoracic and cervical levels lined by a single flattened layer of ependymal cells. Radially directed processes arose from the base of many of the cells and contributed to the formation of the external glial, limiting membrane. Tanycytic processes which terminated on the basal lamina at the pial surface in the manner of a true epithelium formed septa *en route* that enclosed fascicles of longitudinally coursing neurites. Separation of the central canal of the filum from the subarachnoid space by only a single layer of cells and a thin covering of glia lends credence to suggestions that caudally flowing cerebrospinal fluid may readily transfer across this region into the sacral subarachnoid space (Becker *et al.* 1972; Bradbury & Lathem, 1965). When teleost fish are adapted to salt water, dorsally located ependymal cells in the filum canal undergo morphological changes reminiscent of cells participating in the transport of electrolytes suggesting that they may function in maintaining the composition of cerebrospinal fluid (Kriebel, 1981).

The presence of neurons that come into contact with the cerebrospinal fluid in the cord of the rat is consistent with morphological descriptions of similar neurons in the spinal cord of various other vertebrates (Rascher *et al.* 1985; Schueren & DeSantis, 1985; Vigh, Vigh-Teichmann, Manzano e Silva & van den Pol, 1983). Unlike

conditions in other species, however, granular vesicles were not seen within these dendritic terminals in the rat. The terminals were found in the cervical, thoracic and lumbar segments but were not numerous although this may be due in part to the small size of our sample. Rascher *et al.* (1985) recently found similar terminals throughout the length of the cat central canal but potential neurons of origin for these terminals were very few in the vicinity of the ependyma. The function of these CSF-contacting dendrites is still unknown. On the basis of their morphology, a receptor and secretory function has been ascribed to them although there is no conclusive evidence for either (Rascher *et al.* 1985). CSF-contacting neurons in the filum, lumbar, thoracic and cervical cord of the frog were recently shown to stain specifically for tyrosine hydroxylase (Chesler & Nicholson, 1985). Similar neurons juxtaposed to the ependyma in the spinal cord of rats have been shown to contain aromatic-L-amino acid decarboxylase (Jaeger *et al.* 1983) and glutamic acid decarboxylase (Barber, Vaughn & Roberts, 1982).

Unlike the case in mammals, regeneration is known to occur in lower vertebrates and ependyma plays a significant role in the initiation and maintenance of regenerative processes in some species (Turner & Singer, 1973; Simpson, 1964; Bryant & Wozny, 1974). Channels formed between adjacent ependymal cell processes like germinal epithelium provide the pathway for guidance and direction of regenerating spinal cord axons towards their destination (Norlander & Singer, 1978; Simpson, 1968; Anderson, Waxman & Laufer, 1983; Singer, Nordlander & Egar, 1979; Egar & Singer, 1972). Although described primarily in connection with ependyma of amphibians and reptiles this phenomenon has also been noted in mammalian forms. During the period after spinal cord transection in the rat, ependymal cells have been seen to ensheath fascicles of sprouting nerve fibres at the lesion site in an abortive attempt to support the regeneration process (Matthews *et al.* 1979). The filum, because of the predominance of ependymal elements and absence of a complex neuropil, would be a useful preparation to study this phenomenon in mammalian forms.

Proliferation of ependymal cells have also been observed in the mammalian central canal in response to a variety of insults (Kerns & Hinsman, 1973; Matthews *et al.* 1978, 1979; Vaquero, Ramiro, Oya & Cabezundo, 1981; Wallace *et al.* 1983; Bruni & Anderson, 1987; Gilmore & Leiting, 1980). In contrast, experimentally induced lesions of ventricular ependyma in adult animals are largely irreversible and observations suggest a general lack of regenerative capacity in postnatal animals (Fleischhauer, 1972; Garfia *et al.* 1980; Hakansson & von Mecklenburg, 1981; Heinzmann *et al.* 1978). Support for this pattern of differences in the proliferative capacity of ependyma in the spinal cord compared to higher levels of the neuraxis is also found in the clinical literature which indicates that whereas ependymomas constitute 4–6% of all intracranial gliomas, in the spinal cord they constitute the majority (63%) of intramedullary gliomas (Rubenstein, 1972). In the present study, morphological dissimilarities between ependymal cells in the spinal cord and those in the ventricles were not sufficient to explain observed differences in their proliferative capacities. A factor worthy of further investigation, however, is the difference in the numbers of tanycytes in the two locations for they may be the reactive elements that proliferate in response to injury.

SUMMARY

Ependymal cells of the rat central canal were examined with a view to identifying features that distinguish them regionally and from their counterparts elsewhere in the ventricular system. The results revealed that the lining consisted for the most part of a pseudostratified layer of uniformly organised cuboidal to columnar ependymal cells present in largest numbers in lumbar and sacral segments and in the conus. Two cell variants were identified on the basis of the presence or absence of a radially directed cytoplasmic process originating from the base of the cell. The tanycytic form of ependymal cell was encountered along the entire length of the central canal but with increased frequency in caudalmost segments. Ependymal cells were largely similar in ultrastructural appearance along the length of the cord. Although they were also similar in appearance and orientation to their counterparts in the ventricles they did exhibit some unique features. The most notable were the prominent junctional complexes and associated filaments present along the lateral border of the cells near their apex and the abundance of intermediate filaments in tanycytes. The central canal of the filum differed most markedly from other segments of the cord and resembled in structure the primitive ependymal tube of the caudal cord in lower vertebrates. Ependymal cells of the cord were not sufficiently dissimilar morphologically from their counterparts in the ventricles to account for differences in proliferative capacity in response to localised injury. A factor that merits further study is the difference in numbers of tanycyte ependymal cells in the two locations for they may be the reactive elements that proliferate in response to injury.

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