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EFFECT OF HYPOTHYRODISM ON THE EPENDYMA OF SPINAL CORD OF RAT

(With 21 Figures)

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تأثير نقص هرمون الغدة الدرقية على الطبقة المبطنة للحبل الشوكي في الفئران

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تم دراسة تأثير نقص هرمون الغدة الدرقية على نضج وتمايز الطبقة المبطنة للقناة المركزية للحبل الشوكي في الفئران. إستخدم في هذه التجربة ٤٠ حيوان على إمتداد المرحلة العمرية من بعد الولادة وحتى عمر ٤٢ يوم. قسمت الحيوانات لمجموعتين أخذت إحداهما كمجموعة ضابطة والأخرى وضعت تحت المعاملة حيث حقنت يومياً تحت الجلد بجرعات وتركيزات معلومة من مادة اليوروبيل ثيوبوراسيل لإحداث حالة نقص هرمون الغدة الدرقية. تم إعدام الحيوانات عند عمر ٤، ١٠، ٢١، ٣٥، ٤٢ يوم. بعد الفحص والدراسة شوهدت تغيرات مورفولوجية واضحة في خلايا البطانة العصبية للحيوانات تحت المعاملة على امتداد النخاع الشوكي. مقارنة بالأعمار المختلفة في الحيوانات غير المعاملة وجد أن البطانة العصبية للحيوانات التي تعانى من نقص هرمون الغدة الدرقية بدت أقل تمايزاً من مثيلتها عند نفس العمر في المجموعة الضابطة. وأيضاً لوحظ أن هناك نقص في المتقدرات وزيادة في الشبكة الهيولية الباطنة الخشنة و إختلافات في شكل الأنوية. كما أنه لاتوجد أي علامات للإنقسام في خلايا البطانة العصبية لهذه الحيوانات المعاملة. وقد لوحظ أيضاً أن هناك عدم انتظام في سطح الخلية مصاحب بتنكيس في الزغيبات وفقد الأهداب بجانب أن هناك تفكك ملحوظ في الأجسام عديدة الريبسات إلى أحادية الريبسات وكذلك في كثير من التراكيب الحويصلية والخيطية. كما لوحظ أن عدد البصيلات فوق البطانة العصبية قليل وأن الإلتصاق المركب بين خلايا البطانة العصبية فقد نظامه وهناك أيضاً تغيرات واضحة في سيتويلازم الخلايا فوق البطانة العصبية. وشوهدت أيضاً تغيرات واضحة وعدم انتظام في الخلايا المميلنة وعديمة الميلين وأجسام بجبيلة المحور الصفائحية في الحيوانات تحت المعاملة. ويتضح من نتائج هذه التجربة أن نقص هرمون الغدة الدرقية يؤثر بصورة واضحة على نمو وتمايز خلايا الطبقة المبطنة للنخاع الشوكي في الفئران.

SUMMARY

Effect of neonatal hypothyrodism on maturatian and differentiation of ependyma of rat spinal cord was studied. A state of hypothyrodism was induced in rats by subcutaneous injections of propylthiouracil (PTU). Morphological changes of ependymal cells were observed up to 42 days of age, and no specific regional variations did exist. Compared with the age-matched control rats, the spinal ependyma of hypothyroid rats was less differentiated. Ependymocytes of hypothyroid animals showed scarcity of mitochondria, more RER, less nuclear pleomorphism and no mitotic forms were detected. There were also coinciding surface irregularities associated with microvillar degeneration and deciliation. There were also marked dissociation of polyribosomes into monosomes, many vesicular structures and abundant microfilaments. The supraependymal neuronal bulbs were less frequent. Junctional complexes between ependymocytes were disorganized. The subependymal neuronal cells showed cytoplasmic abnormalities. The associated myelinated and unmyelinated neurofibers had less organized neurofilaments and axoplasmic lamellated bodies. It was concluded that hypothyroidism as a hormonal insult affects maturation and differentiation of spinal ependyma of rat.

Key Words: *Hypothyrodism- Rat- Spinal cord- Ependyma- Ultrastructure .*

INTRODUCTION

Ependyma is the lining layer of the brain ventricles and the central canal of the spinal cord, derived from the internal lining of the neural tube. The other cells of the neural tube develop processes and give rise to neurons or to neuroglia (Unqueira and Carneiro, 1980; Leeson , Leeson and Paparo, 1988).

Brain ventricular ependyma has been studied extensively and reviewed by many authors (Booz, 1975; Stumpf, Hellreich, Aumuller and Lamb, 1977; Hetzel, 1978; Agnew, Aluarez, Yuen and Crews, 1980; Leonhardt, 1980; Low, 1982). Few reports have dealt with the morphology of the spinal canal ependyma and its embryonic and postnatal development (Gilmore, Sims and Leiting, 1981; Seitz, Lohler,

and Schwendenmann, 1981; Sturrock, 1981; Bruni and Reddy, 1987; Roger, Hans and Per, 1988; Sana, 1991).

Thyroid hormones have significant effects on the growth, development and the normal metabolic processes of all body systems especially the nervous system (Hamburg, Lynn and Weiss, 1964; Eayrs, 1968 and 1971; Rebiere and Dainat, 1976; Lu and Brown, 1977; David, 1979; Davied and Nathaniel, 1981 and 1983). Thyroxines, T3 and T4, play a profound role in differentiation of various cell types in rat spinal cord (Oppenheimer, 1979).

The effect of hypothyroidism especially on differentiation and maturation of spinal canal ependyma was not reported before. Hence, the present work was designed to elucidate the effect of thyroid hormone deficiency on this nervous element.

MATERIALS and METHODS

40 litters of Sprague-Dawley rats from a highly inbred colony were divided into two groups. Pups in group 1 (n= 30) were given daily subcutaneous (SC) injections of propylthiouracil (PTU) (Sigma) in physiological saline according to the following schedule: 0.05 ml of 0.2% PTU on days 0-10, 0.1 ml of 0.2% PTU on days 11-20, 0.1 ml of 0.4% PTU on days 21-30, 0.2 ml of 0.4% PTU on days 31-42. The following table shows the injection schedule:

Age (days)	Dose (ml)(%)
0 -10	0.05 (0.2%)
11- 20	0.1 (0.2%)
21-30	0.1 (0.4%)
31- 42	0.1 (0.4%)

Group 2 (n=10) served as control. Six animals from group 1 and 2 animals from group 2 at 4, 10, 21, 35 and 42 days of age were anaethesitized and perfused intracardially with Karnovsky's fixative at pH 7.2. Thin slices of the spinal cord were, placed in the same fixative for an hour, and postfixed in 1% osmium tetra-oxide for 100 min. Following dehyderation in ascending grades of ethanol, the tissues were

embedded in Araldite. For the purpose of tissue orientation, semi-thin sections (1μm) were prepared and stained with toluidine blue. Ultra-thin sections were subsequently made, double stained with uranyl acetate and lead citrate and examined under transmission electron microscope (TEM) (JEOL, 100 CX II) operated at 80 Kv.

Thyroid glands were removed at the time of killing for light microscopic studies. The lack of colloid and the presence of hyperplastic follicular epithelium were used as criteria in considering the animals to be hypothyroid.

RESULTS

Spinal ependyma of control rats (Figs. 1, 2):

The specimens of the control rats at the studied ages showed common histological characteristics. The spinal canal was round or ovoid in cross section and lined with ependymal cells of pseudostratified columnar type. The cerebrospinal fluid contacting surface of ependymal cells had brush broder due to presence of arrays of cilia and microvilli which also covered the occasional cytoplasmic protrusions exhibited by ependymocytes. Each ependymal cell had 1-2 kinocilia which measured 0.25 μm in diameter and 8-10 μm in length. Supra-ependymal neuronal bulbs appeared as surface projections on the luminal surface of ependymal cells. Nuclei of ependymocytes were found in a mediobasal position and contained predominent eu- and hetero-chromatin along the nuclear membrane. The most conspicuous organelle in ependymal cell cytoplasm was mitochondria of crista type which were dispersed in the apical cytoplasm. Rough endoplasmic reticulum was sparse and not prominent. Golgi apparatus was located in the middle and apical parts of ependymal cells. The neighbouring ependymocytes were connected to each other by junctional complexes (zonula adherens, zonula occludens-like junctions and gap junctions) near the apical parts.

Some ependymal cells had basal radiating processes, containing neurofilaments and few mitochondria that separated and partially ensheathed a group of myelinated fibers in the neuropil. The processes of these tancytes were surrounded by axons and dendrites of the sub-ependymal neurons but separated from them by thin astrocytic lamellae. There were also axo-somatic and axo-dendritic synapses. Two variants of sub-ependymal neuronal cells were observed. The first had long

dendritic processes which extended between ependymal cells to contact with the luminal surface of spinal canal (cerebrospinal-fluid-contacting neurons or subependymal somata). The supra-ependymal neuronal bulbs had continuity with the CSF-contacting neurons. The second variant of the subependymal neurons is that which had no such dendritic processes. The zone just beneath the ependymal lining cells had a vacuolated appearance due to presence of many parallel groups of neurites in a glomerulus- like arrangement.

Spinal ependyma of hypothyroid rats:

In 4 and 10-day-old neonates, nuclei of ependymal cells were more elongated and less indented with increasing density of nuclear chromatin (Fig. 3). There was a sort of shift of the subependymal neurons towards the central canal of the spinal cord. The lumen of the central canal of cervical segments was slightly reduced in size in some cases. Light and electron microscopy at the age of 10 days revealed obviously the elongation of nuclei and the deterioration of the microvilli on the surfaces of the ependymal cells (Figs. 4 & 5).

At 21 days of age, elongation of ependymal cells nuclei was still observable with less condensation of nuclear chromatin. Central canal of the cervical cord was occasionally seen collapsed (Fig. 6) with adhesion of the apical protrusions from the apposing ependymocytes. The subependymal neuronal cells were less approximated in the collapsed parts. Ultrastructurally, nuclear elongation was apparent. Mitochondria in the ependymal cells were reduced in size, Golgi complexes showed saccular dilatations and numerous polyribosomes and occasional lipid droplets were seen in cytoplasm of ependymal cells (Figs. 7, 8 & 9). Nuclear membranes were occasionally evaginated leaving perinuclear spaces. Wide surface areas revealed deciliation and microvillar degeneration. Basal processes of ependymal cells (tancytes) were less pronounced and incompletely enveloping the underlying myelinated and unmyelinated nerve fibers. The subependymal unmyelinated fibers revealed degeneration of their neurofilaments with the presence of electron-dense lamellated structures (Fig. 10). In the ependymal cells cytoplasm and in the vicinity of the unmyelinated fibers, there were glycogenic granular deposits. The dendritic processes of the subependymal neurons, which extend between ependymal cells, contained elongated degenerated mitochondria, many microfilaments and vesicular structures (Fig. 11).

More or less similar microscopic changes to those described at 21 days of age were noticed at day 35 th. Oedema was seen separating the subependymal elements and extended to neuropil. The nuclei of ependymal cells were relatively elongated and due to indistinction of nucleoli the vesicular appearance of the nuclei was less apparent (Fig. 12). Nuclear indentation was observed only in some ependymocytes (Fig. 13). Deciliation and microvillar deterioration were more diffuse. There were fewer segments of RER and most of the mitochondria were atrophied. Golgi complexes at the juxtanuclear areas in ependymocytes were less distinct (Fig. 14). Nuclei of the subependymal neurons were enlarged.

At 42 days of age, blebbings from the apical cytoplasm of ependymocytes were frequent (Fig. 15). Microvilli covering the surface blebbings were elongated and most of ependymal cells were devoid of cilia except for few abnormally embedded cilia. The junction complexes between the ependynocytes were markedly disorganized and frequently closer to each other. The supra-ependymal neuronal bulbs contained fewer mitochondria and vesicular structures but many neurofilaments (Fig. 16). Nuclei of ependymal cells were less pleomorphic and no evidence of mitosis except for some nuclear indentations (Fig. 17). There was scarcity of mitochondria but in some ependymocytes mitochondria were markedly elongated in association with numerous mono- and polyribosomes (Fig. 18). Multivesicular bodies, vacuoles and lysosoamal-like structuces were abundant in the cytoplasm of some ependymal cells (Fig. 19). Tancytes had abundance of polyribosomes, glycogenic deposits and dilated Golgi complexes. The supra-ependymal neuronal bulbs were less frequent and if present the junction complexes between them and the adjacent ependymal cells were indistinct.

Subependymal neurons contained numerous polyribosomes, glycogen, many stacks of RER and dilated Golgi complexes (Fig. 20). Myelinated and unmyelinated nerve fibers subjacent to subependymal neuronal cells were obviously degenerated. The myelinated fibers had disorganized neurofilaments and glycogen deposits while the unmyelinated ones had degenerated mitochondria, less neurofilaments and lamellated structures (Fig. 21). The axodendritic synapses were separated.

In general, at 35 and 42 days of age differentiation of the spinal ependymal cells were less expressed if compared with control. This was

evidenced by the existence of less number of indented nuclei, abnormal shaped nuclei, less peripheral nuclear chromatin, less vesicular nuclei due to indistinction of nucleoli, sparse mitochondria and easily identified primitive Golgi complexes. The less differentiated ependymal cells of hypothyroid rats showed also increased surface irregularities associated with deciliation and microvillar degeneration.

DISCUSSION

In the present hypothyroid rats, all segments of the spinal cord basically showed similar morphopathological changes and no specific regional variations were found. This may be attributable to the similar structure of the rat central canal along the length of the spinal cord (Bruni and Reddy, 1987). The junctional complexes connecting the ependymal cells in the control cases seemed to be tight and of high strength. It was proposed that the considerable number of cell junctions connecting ependymocytes indicates a pronounced ionic or metabolic coupling of these cells (Agnew et al., 1980). Accordingly, the observed disorganzation of cell junctions at 42 days of age in treated cases may affect this coupling.

Compared with the present control animals and those reported by Sana (1991), the spinal ependyma of the hypothyroid rats in this sutdy showed some histological abnormalities. Scarcity of organelles, less prominence of nuclear pleomorphism, deciliation and microvillar deterioration were among the noticeable features at the different studied postnatal periods.

The present ependymal changes bear some similarities to the neuronal cell changes of neonatal hypothyroid rats reported by Lu and Brown (1977) and David and Nathaniel (1983). The neurons of the hypothyroid rats displayed cytoplasmic vacuolation, drastic reduction in cytoplasmic organelles and dissociation of polyribosomes into monosomes. Similarly, the myelinated axons of hypothyroid rats were degenerated and contained glycogen granules, vacuoles and lamellar bodies (reactive axons).

It has been postulated that significant reduction of organelles in neurons of hypothyroid rats is indicative of reduced protein synthesis as substantiated by the biochemical studies (Balazs and Gaitonde, 1968 ;

David and Nathaniel, 1983). Similar effect of hypothyroidism can be also assumed in the present hypothyroid cases.

Changes such as axonal atrophy, increased myelin thickness and decreased number of neurofilaments in neurofibers of hypothyroid rats were supposed to be signs of a low grade degenerative process (David and Nathaniel, 1983).

Currently, oedema was noticed in the spinal subependymal structures and neuropil. This associated the alterations of ependymal cells and their junctional complexes, therefore we presume a relation between existence of oedema and changes of ependymal cells.

No definite function of ependymal cells has been identified, but among the proposed functions are diffusion barrier, secretion, mechanical support. transcellular and ciliary transport (Bjugn et al., 1988). According to the later authors, functions such as transcellular transport and secretion seem unlikely by the spinal cord ependyma basing upon its structure and intracellular components. These authors assume that ciliary transport is the sole physiological function of spinal ependyma. In this respect, normal rat spinal ependyma has a profusion of microvilli and 1-4 cilia / cell arising from the luminal surface along the entire length of the central canal (Bruni and Reddy, 1987).

Deciliation observed in the present cases undoubtedly affects the proposed ciliary transport. It was believed that spinal ependymal cells by their filamentous content serve as a support protecting the spinal canal lumen from compression produced by flexion of the vertebral column (Kohno, 1969). Thus, if ependymal cells are altered, as observed herein, they no longer can perform this support function and the spinal canal would be more vulnerable for collapse.

It is suggested that central spinal canal may serve as an alternate route for CSF reabsorption and also play a role in CSF circulation in general. (Becker, Wilson and Watson, 1972; Torvik and Murthy, 1977; Scitz et al., 1981). The present microvillar changes and other surface alterations can affect to a large extent the suggested role of the spinal ependyma in the circulation of CSF.

The CSF-contacting dendrites were said to have receptor and secretory functions (Rascher, Booz, Nacimiento and Donauer, 1985). If this is true, then the present dendritic changes can disturb these functions. It is known that the long basal processes of ependymal cells (tancytes) which extend between neural elements in brain and spinal cord

constitute a supporting matrix (Unqueira and Carneiro, 1980). The currently observed ependymal cell alterations also involved the basal processes and thus the supporting role could be minimized.

No evident signs of ependymal cell mitosis were seen in any of the hypothyroid animals. This may indicate a slow regenerative capacity of the spinal ependymal cells in case of hypothyroidism. Some workers (Adrian and Walker, 1962; Kerns and Hinsam, 1973; Matthews, St. Onge and Faciane, 1979; Gilmore and Leiting, 1980; Bruni and Anderson, 1987) found that proliferation of spinal ependyma of mammalian species, unlike the cerebral ventricular ependyma, is a common response to spinal cord injury.

Appearance of glycogen granules and decreased number of mitochondria in the ependymal cells and unmyelinated axons in the present hypothyroid cases may indicate a shift from aerobic to anaerobic energy yielding mechanisms. Glycogen and mitochondria are considered as morphologic markers for anaerobic and aerobic pathways, respectively (David and Nathaniel, 1983). Alternatively, appearance of glycogen deposits may be ascribed to decreased utilization of glycogen or an increased dependence on anaerobic mechanisms.

Conclusively, the presently demonstrated postnatal ependymal morphological changes may be ascribed largely to the lack of thyroid hormone in the treated rats. Thus, the resultant ependymal alterations are considered to be a reaction to a hormonal insult.

REFERENCES

Adrian, E.K. and Walker, B.E. (1962): Incorporation of thymidine - 3H by cells in normal and injuried mouse spinal cord. Journal of Neuropathology and Experimental Neurology, 21, 597-609.

Agnew, W.F., Aluarez, R.B., Yuen, T.G. and Crews, A.K. (1980): Protein synthesis and transport by the rat choroid plexus and ependyma. Cell and Tissue Research, 208, 261-281.

Balazs, R. and Gaitonde, M.K. (1968): Factors affecting protein metabolism in the brain. Bioch. J., 106, 1-2P.

Becker, D.P., Wilson, J.A. and Watson, G.W. (1972): The spinal cord central canal response to experimental hydrocephalus and canal occlusion. Journal of Neurosurgery, 36, 416-424.

Bjugn, R., Haugland, H.K. and Flood, P.R. (1988): Ultrastructure of the mouse spinal cord ependyma. Journal of Anatomy, 160, 117-125.

Booz, K.H. (1975): Secretory phenomena at the ependyma of the III rd ventricle of the embryonic rat. Anatomy and Embryology, 147, 143-159.

Bruni, J.E. and Anderson, W.A. (1987): Ependyna of the rat fourth ventricle and central canal: response to injury. Acta anatomica,

Bruni, J.E. and Reddy, K. (1987): Ependyma of the central canal of the rat spinal cord : a light and transmission electron microscopic study. J.Anat., 152, 55-60.

David, S. (1979): Postnatal development of the cuneate nucleus in euthyroid and hypothyroid rats an ultrastructural study. PH.D Thesis, University of Manitoba.

David, S. and Nathaniel, E.J.H. (1981): Development of brain capillaries in euthyroid and hypothyroid rats. Exp. Neurol., 73, 243-253.

David, S. and Nathaniel, E.J.H. (1983): Neuronal changes induced by neonatal hypothyroidism: An ultrastructural study. The American Journal of Anatomy, 167, 381-394.

Eayrs J.T. (1968): Developmental relationship between brain and thyroid. In: Endocrinology and Human Behaviour. R.P. Michael (Editor). Pp. 239-255. Oxford University Press (London).

Eayrs, J.T. (1971): Thyroid and developing brain: anatomical and behavioural effects. In: Hormones in Development. M. Hamburgh and E.J.W. Barrington (Editors). Pp. 345-355. Appleton - Century - Croft (New York).

Gilmore, S.A. and Leiting, J.E. (1980): Changes in the central canal of immature rats following spinal cord injury. Brain Research, 201, 185-189.

Gilmore, S.A., Sims, T.J. and Leiting, J.E. (1981): Central canal area in the early postnatal rat: Normal development and radiation induced changes Developmental Brain Research, 14, 149-157.

Hamburg, M.; Lynn, E. and Weiss, E.P. (1964): Analysis of the influence of Thyroid hormone on prenatal and postnatal maturation of the rat. Anat. Rec. 150: 147-162.

Hetzel, W. (1978): Ependyma and ependymal protrusions of the lateral ventricles of the rabbit brain. Cell and Tissur Research, 192, 475-488.

Kerns, J.M. and Hinsman, E.J. (1973): Neurological response to sciatic neurectomy. I. Light microscopy and auto radiography. Journal of comparative Neurology, 151, 237-254.

Kohno, K. (1969): Electron microscopic studies on Reissner's fiber and the ependymal cells in the spinal cord of the rat. Z.Zell forsch, 94, 565-573.

Leeson, T.S., Leeson, C.R. and Paparo, A.A. (1988): Text Atlas of Histology. 3 rd Edition. W.B. Saunders Company (Philadelphia, London, Toronto).

Leonhardt, H. (1980): Ependyma und circumventriculare organe. In: Handbuch der mikroskopischen Anatomie de Mensche, Band IV, 10 Teil, Neuroglia. A. Oksche & L. Vollrath, (Editors). Pp. 177-666. Springer (Berlin, Heidelberg).

Low, F.N. (1982): The central nervous system in scanning electron microscopy. Scanning Electron Microscopy, I, 869-890.

Lu, E.J. and Brown, W. J (1977): An electron microscopic study of the developing caudate nucleus in euthyroid and hypothyroid states. Anat. Embryol., 105, 335-364.

Matthews. M.A., St. Onge, M.F. and Faciane, C.L. (1979): An electron microscopic analysis of abnormal ependymal cell proliferation and envelopment of sprouting axons following spinal cord transection in the rat. Acta Neuropathologica, 45, 27-36.

Oppenheimer, J.H. (1979): Thyroid hormone action at the cellular level. Science, 203:971-979.

Rascher, K., Booz, K.H., Nacimiento, A.C. and Donauer, E. (1985): The ependyma of the cat central canal with particular reference to its mitochondria containing bulbs. Scanning Electron Microscopy I, 231-238.

Rebiere, A. and Dainat, J. (1976): Etude ultrastructurale quantitive due pericoryon de la cellule de purkinje et de so environment chez le rat normal et hypothyroidien ages de 21 jours. Exp. Brain Res., 25, 511-527.

Roger, B., Hans K.H. and Per, R.F. (1988): Ultrastructure of the mouse spinal cord ependyma. J. Anat., 160, 117-125.

Sana, A.M.A (1991): The development of the ependyma of the rat spinal cord, light and electron microscopic study. The Egyptian Journal of Histology, 14, 157-169.

Seitz, R., Lohler, J. and Schwendenmann, G. (1981): Ependyma and neninges of the spinal cord of the mouse. A light and electron nicroscepic study. Cell Tissue Res., 220, 61-72.

Stumpf, W.E., Hellreich, M.A., Aumuller, G. and Lamb, J.C. (1977): The collicular recess organ : Evidexe for structural and secretory specialization of the ventricular lining in the collicular recess. Cell and Tissue Research, 184, 29-44.

Sturrock, R.R. (1981): An electron microscopic study of the development of the ependyma of the central canal of the mouse spinal cord. Journal of Anatomy, 132, 119-136.

Torvik, A. and Murthy, V.S. (1977): The spinal cord central canal in kaolin induced hydrocephalus. Journal of Neurosurgery, 47, 397-402.

Unqueira, L.C. and Carneiro, J. (1980): Basic Histology. 3rd Ed. Huntsmen Offset Printing Ltd (London, Toronto).

LEGENDS OF FIGURES

Fig. 1: Ependyma of spinal cord (cervical segment) of a control 4-day-old rat. The ependymal cells are of pseudostratified columnar type and their nuclei (n) are situated in mediobasal position. The spinal canal (sc) is ovoid in shape. The luminal surface of ependymocytes has brush border due to presence of cilia and microvilli. There are subependymal neruonal cells (arrows) which have dendritic processes extending in the neuropil (np) and some have dendritic processes extending to the central canal (CSF-contacting neurons). The latter processes are terminated by bulging parts (supra-ependymal bulbs) (arrowhead). The subependymal tissue contains many myelinated and unmyelinated neruofibers. Toluidine blue stain X 125.

Fig. 2: Survey transmission electron micrograph of the lining ependyma of spinal canal of 10-day-old control rat. The nuclei (n) of the ependymal cells have finely granular chromatin, chromain masses along the nuclear membrane and nucleoli. Cytoplasm of ependymocytes contains large number of mitochondria (m), Golgi complexes (g) and dispersed segments of RER (r). There

is a profusion of microvilli at the luminal surface of ependymocytes. Base of a kinocillium (arrow) is seen. X4000.

Fig. 3: Spinal ependyma of 4-day-old hypothyroid rat. Nuclei (n) of ependymocytes are more elongated with more dense chromation aggregates. The subependymal neuronal cells (arrows) are more approximated and the surrounding neuropil is edematous. Spinal canal (sc) is reduced in size. Note the Reisner's fibers (arrowhead) in the central canal. Toluidine blue stain. X 125.

Fig. 4: Ependymal cells of 10-day-old hypothyroid rat showing more elongated nuclei (n). The subepenymal neurons (arrows) are more approximated. Note the distinct dendritic process (arrowhead) which extend between ependymal cells.. Toluidine blue stain. X125.

Fig. 5: Transmission electron micrograph of 10-day-old hypothyroid rat showing degeneration of microvilli (v) and obvious elongation of ependymal cells nuclei (n). Note the subependymal neuronal cell (nc) which is separated from the ependymal cell by fine astrocytic processes. X 4000.

Fig. 6: Occasional collapse of the central spinal canal of the cervical segment. The apical protrusions of the apposing ependymocytes are adhesed. The surrounding neuropil is edematous. 21-day-old hypothyroid rat. Nuclei (n) of the ependymal cells are still elongated. Toluidine blue stain. X 125.

Fig. 7: Ependymal cells with reduced-sized mitochondria (m) and deteriorated microvilli (v). The subependymal neuronal cell (nc) is swollen. 21-day-old hypothyroid rat. Transmission electron micrograph. X 4000.

Fig. 8: Ependymal cell showing saccular dilatations of the Golgi complexes (g), numerous polyribosomes and monosomes (from dissociated polyribosomes) and marked deterioration of microvilli (v). 21-day-old hypothyroid rat. Transmission electron micrograph. X 5000.

Fig. 9: Ependymal cells containing atrophied mitochondria (m) and occasional lipid droplets (L). Microvilli (v) are obviously deteriorated. Some nuclei (n) of ependymal cells have dense marginated chromatin masses. 21-day-old hypothyroid rat. Transmission electron micrograph. X 4000.

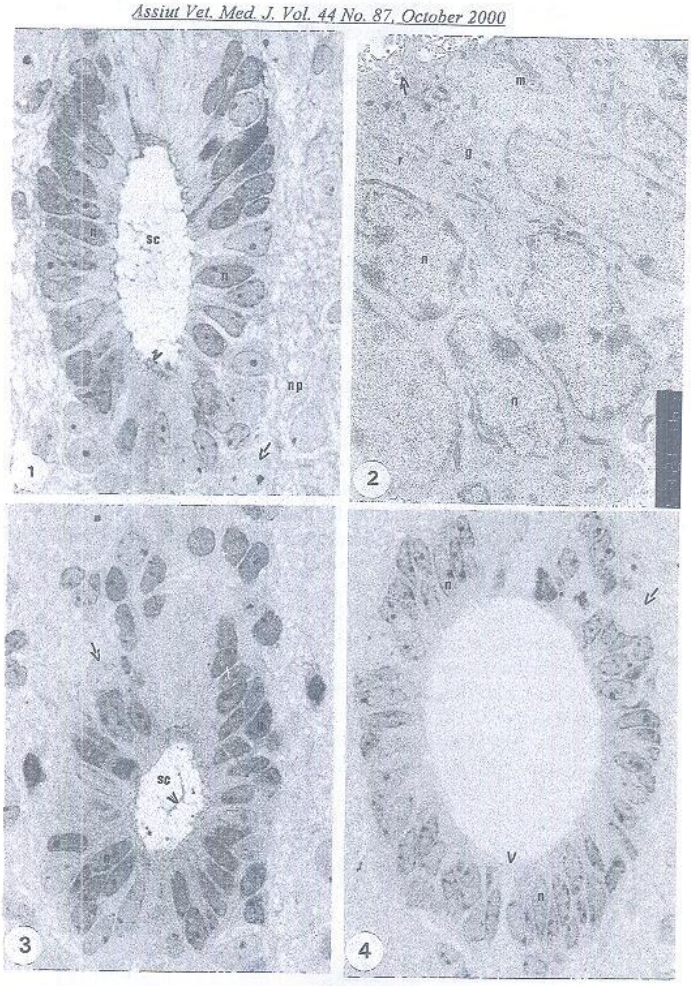
Fig. 17: Ependymal cells with some indented nuclei (n) which have marginal chromatin condensations. 42-day-old hypothroid rat. Transmission electron micrograph. X 4000.

Fig. 18: Obviously elongated mitochondria (m), many polyribosomes and few dilated segments of RER in cytoplasm of an ependymal cell. Numerous microfilaments are also seen. 42-day-old hypothyroid rat. Transmission electron micrograph. X 14.000.

Fig. 19: Vacuolar structures (vs) containing fine granular material and lysosomal-like structures (Ls) in cytoplasm of an ependymal cell (tancyte). Note the numerous monosomes and glycogen granules. The axo-dendritic synapses (s) are separated. 42-day-old hypothyroid rat. Transmission electron micrograph. X14000.

Fig. 20: Subependymal neuronal cell (nc) containing numerous polyribosomes and monosomes, dilated Golgi complexes (g) and dilated segments of RER (r). Hypothyroid rat at 42 days of age. Transmission electron micrograph. X14000.

Fig. 21: Myelinated neurofibers (mn) containing disorganized neurofilaments. The unmyelinated fibers (uf) have decreased number of neurofilaments and lamellated structures. 42-day-old hypothyroid rat. Transmission electron micrograph. X 10.000.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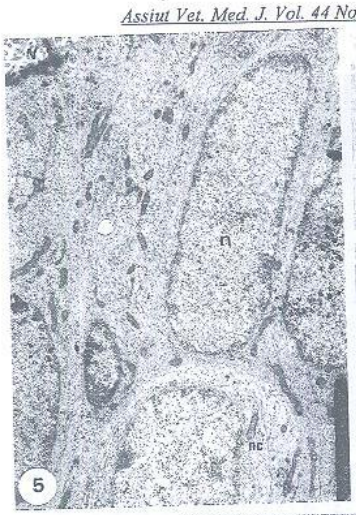

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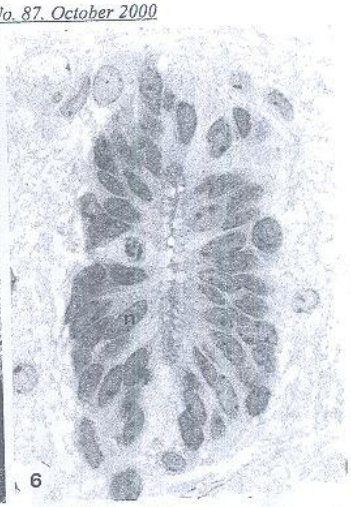

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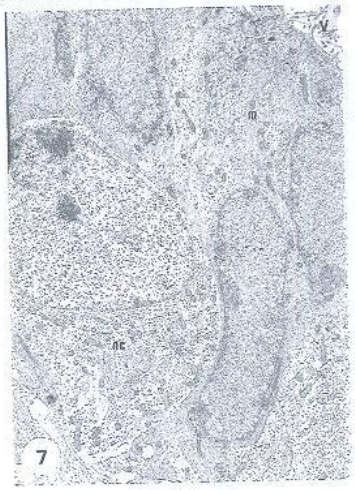

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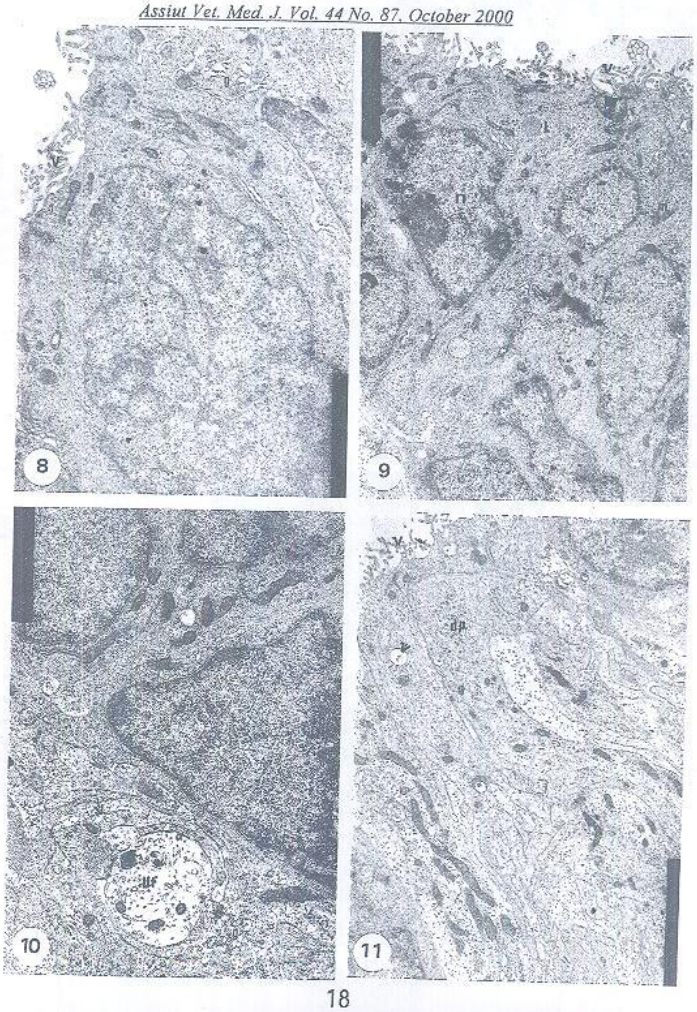
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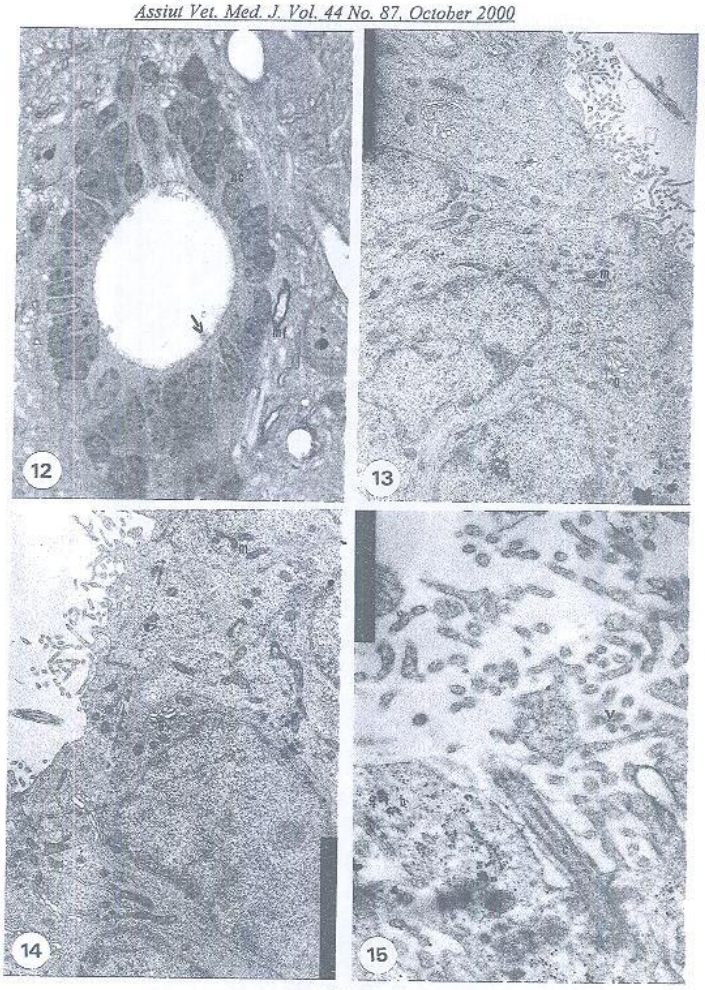
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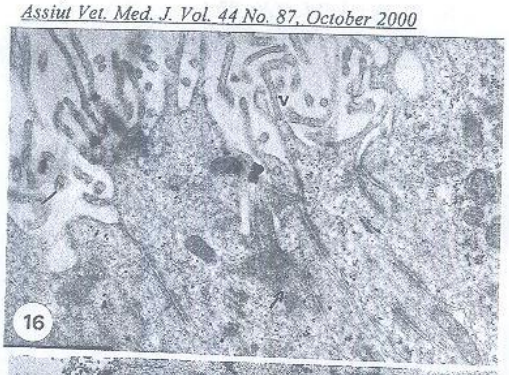
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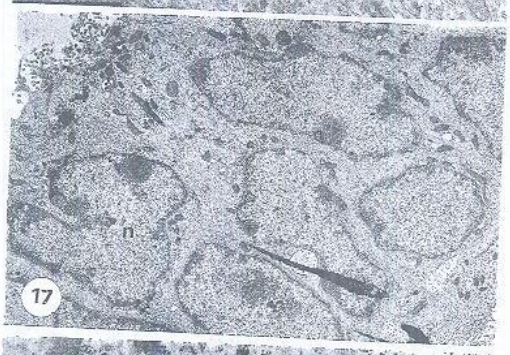
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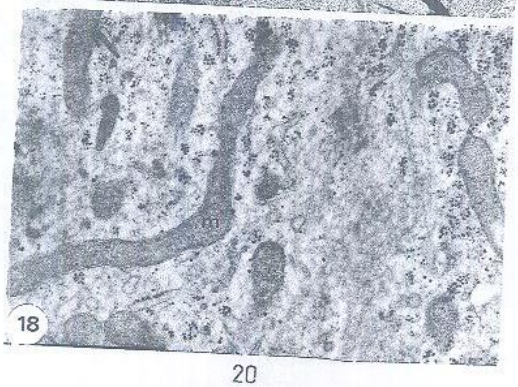
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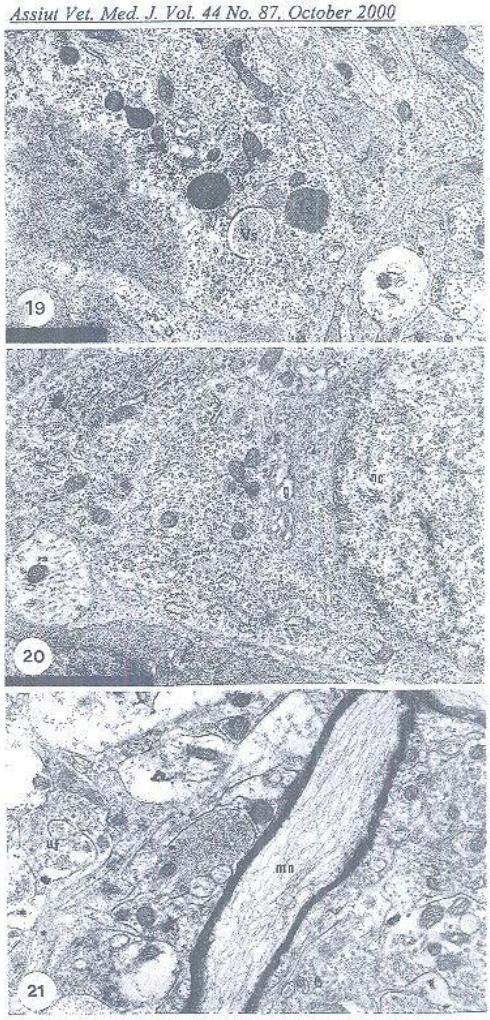

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