Intrinsic innervation and dopaminergic markers after experimental denervation in rat thymus

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Abstract

The aim of this study was to examine rat thymus innervation using denervation techniques and to explore the related micro-anatomical localization of dopamine, D1, D2 receptors and dopamine membrane transporter (DAT).

In the thymus subcapsular region, the parenchymal cholinergic fibers belong exclusively to phrenic nerve branching. No somatic phrenic nerve branching was detected in any other analysed thymus lobule regions.

In rats subjected to sympathetic or parasympathetic ablation, it was observed that catecholaminergic and cholinergic nerve fibers respectively contributed to forming plexuses along vessel walls.

In the subcapsular and septal region, no parenchymal nerve branching, belonging to sympathetic or parasympathetic nervous system was noted. Instead, in the deep cortical region, cortico-medullary junction (CM-j) and medulla, catecholaminergic and cholinergic nerve fibers were detected along the vessels and parenchyma.

Dopamine and dopamine receptors were widely diffused in the lobular cortico-medullary junction region and in the medulla, where the final steps of thymocyte maturation and their trafficking take place.

No variation in dopamine and DAT immune reaction was observed following total or partial parasympathectomy or phrenic nerve cutting. After chemical or surgical sympathectomy however, neither dopamine nor DAT immune reaction was noted again. Instead, D1 and D2 dopamine receptor expression was not affected by thymus denervation.

In rats subjected to specific denervation, it was observed the direct intraparenchymal branching of the phrenic nerve and sympathetic and parasympathetic fibers into thymus parenchyma along vessels. These findings on the dopaminergic system highlight the importance of neurotransmitter receptor expression in the homeostasis of neuroimmune modulation.

Introduction

Experimental studies have shown that the neuronal pathway is involved in the control of immune responsiveness at several levels, from cellular functions and interactions to overall immunological responses.[1-3]

The anatomical innervation of the thymus is rather complex, because it follows multiple nerve pathways. The sympathetic component reaches the thymus through the perivascular plexus, which originates from the stellate ganglion, which is in turn formed by the fusion of the third cervical ganglion together with the first thoracic ganglion. The parasympathetic component reaches the thymus through the fibers running into the vagal branches of the superior and inferior (or recurrent) laryngeal nerve. Another minor component of thymus nerve supply is the phrenic nerve, a somatic nerve originating in the cervical plexus.[4-6]

Sympathetic and parasympathetic nerve fibers enter the thymus along with blood vessels and branch into the cortex, the capsular and septal system, the cortico-medullary junction and the medulla.[7] Some of the catecolaminergic fibers leave vessels and then branch into thymus parenchyma.[2]

Up to date, the sympathetic system has been considered the most important component of thymus innervation in controlling thymus function, mainly via noradrenergic fibers.[8] The intraparenchymal branching nerve profile has been well visualized[2] and the related central nervous system nuclei well mapped.[9] However, recent evidence has pointed out an important role of the cholinergic pathways as well,[10-15] although parasympathetic intraparenchymal innervation is still questioned. In fact, an unquestionable neuroanatomical evidence of a parasympathetic or vagal nerve supply to the thymus has not yet been found. Whilst some authors have reported anatomical mapping on vagal hindbrain nuclei,[16] or the presence of acethylcholinesterase-positive structures,[17,18] others have not confirmed these findings[9,19] and sentence about a substantial absence of any vagal nerve supply to any immune organs.[8] Similar disagreements concern data interpretation following the use of fluorescent tracer and horseradish peroxidase retrograde

labelling[16] or retrograde transneuronal virus tracing.[9]

Several classic neurotransmitters and neurotransmitter receptors have been found in thymocytes and other thymus cells, supporting the bidirectional communication between the brain and the immune systems.[3] Pharmacological experiments have provided evidence of the muscarinic receptors role in differentiating thymocytes into cytolytic (CD8+) T lymphocytes.[15] It is thought that the mechanism responsible for lymphocyte release from the thymus involves vagal fibers running in the recurrent laryngeal nerve and mediated by nicotinic receptors.[11]

Recent studies have found expression of dopamine, dopamine receptors and transporters in thymus, suggesting a role of dopamine in the maturation and selection of lymphocytes and the activation of immune response.[20,21] Indeed, other studies have pointed out dopamine and noradrenaline co-release by sympathetic fibers innervating cortico-medullary and medullary regions.[22,23]

It has been observed that the effect of dopamine on proliferation and cytotoxity of CD4+ and CD8+ lymphocytes *in vitro* is mediated by the D1 class of receptors,[24] and expression of D3 and D2 receptor subtypes has been found in lymphocyte outer membranes.[25] D1 and D2 receptors are the most widespread receptors types in the dopaminergic system, performing intracellular events, and acting by different pathways.

The aims of this study were to examine the relationship between sympathetic and parasympathetic intraparenchymal nerve distribution in a rat model using experimental denervation techniques, as well as to perform microanatomical localization of dopamine D1 and D2 receptors and dopamine membrane transporter (DAT) in distinct regions of thy-

mus lobules. This work sought to address the discrepant observations about thymus innervation,[8,19] using histochemical techniques and monolateral surgical or chemical removal of thymus innervation, and to resolve the disagreement about some methodological analyses, too.[19,26]

Materials and Methods

Animals

Experiments were performed on 28 Sprague-Dawley male rats (2 months old; weighing 238±21 g; Charles River, Calco, Como, Italy). Animals were housed for four weeks before the experiments, and kept under a constant light-dark cycle (7:00 a.m. to 7:00 p.m. light period), at an ambient temperature of 22±1°C, with food and water available *ad libitum*.

Animals were handled according to internationally accepted principles for care of laboratory animals (E.E.C. Council Directive 86/609, OJL358,1; Dec. 12,1987).

Rats were anaesthetized with pentobarbital sodium (50 mg/kg i.p.); the monitoring eyelid and paw pinch reflexes assessed the adequacy of anaesthesia. When all reflexes were absent, rats were subjected to monolateral surgical or chemical removal of thymus innervation.

Denervation experiments were performed with 6 experimental groups, 4 rats per group. One group was sham operated and used as control group, while the other five groups were treated as follows: surgical sympathectomy, chemical sympathectomy, surgical partial parasympathectomy, surgical parasympathectomy and surgical somatectomy, respectively.

Surgical procedures

Surgical sympathectomy was performed by removal of the star ganglion, the third ganglion of the sympathetic lateral-vertebral chain, in the neck region, on the right side of the vertebral column.

Chemical sympathectomy was obtained by treatment with 6-OH-dopamine (6-OH-DA). The destruction of thymus sympathetic nerve fibers was achieved by partially modifying the guidelines proposed by Angeletti and Levi-Montalcini.[27] Briefly, each rat received an intra-peritoneum injection of 6-OH-DA in physiological solution with 0.5% ascorbic acid as solvent, at doses of 100 mg/Kg/day for 3 days. After 3-5 days, this procedure destroyed almost all the adrenergic nerve fibers of the body including those of the thymus.

The surgical monolateral partial parasympathectomy was performed by right laryngeal superior nerve cutting. The nerve was

approached in its location in the right lateral region of the neck, near the vascular envelopment and the thyroid gland.

The surgical monolateral parasympathectomy was performed by cutting the vagus nerve in its upper course, before it supplies the superior laryngeal nerve.

The surgical monolateral denervation of the somatic nerve was performed by phrenic nerve cutting, approaching the nerve along its course between the mediastinic pleura and the pericardium.

All nerves were cut by removing about 2-3 mm of their length, thus avoiding early regeneration of the fibers. After denervation, animals were allowed to survive for 2 weeks. The efficiency of ganglionectomy was assessed by the onset of ptosis of the eyelid.

Tissue treatment

Animals were anaesthetized and killed by decapitation. The thymus right lobe was removed from each animal, washed in cold phosphate-buffered saline (PBS), then embedded in a cryoprotectant medium and frozen in isopentane cooled with liquid nitrogen. From this specimen, serial sections (10 μm thick, one section per slide) were cut on a cryostat at -20°C. Sections were subdivided into four groups of eight slides each.

The first section of each slide group was processed for hematoxilyn and eosin staining to obtain histopathologic visualization of the tissue.

The second section of each slide group was stained using the Bodian method for frozen sections,[28] being this method quite useful in staining all nerve fibers and neuro-fibrils in the thymus parenchyma.[17] Nerve fibers and neuro-fibrils were stained in black.

The third section of each slide group was processed for histofluorescence staining of catecholaminergic nerve fibers by the method described by Quayyum and Fatani,[29] using the glyoxylic acid-induced fluorescence technique. Further details are reported in previous papers of our group.[30,31]

The fourth section of each slide group was processed for histoenzymatic staining of AChE positive nerve fibers, in accordance to the thyocoline method protocol.[32] Further details are reported in a previous paper of our group.[33]

All sections were analyzed on the same day to prevent diffusion and/or fluorescence photodecomposition.

Immunohistochemistry

The fifth, sixth, seventh and eighth sections of each slide group were used for the immuno-histochemical detection of dopamine (mouse monoclonal antibody, dil. 1:50; Abcam pic, code ab8892; Cambridge, UK), DAT (goat polyclonal

antibody, dil. 1:1000; Santa Cruz Biotechnology, Santa Cruz, Ca, USA), D1 (rabbit polyclonal antibody, dil. 1:500; Chemicon, No. AB 1765P), and D2 (goat polyclonal antibody Santa Cruz Biothecnology, No. sc-7522). Sections were incubated for 1 h at 4°C in a 3% normal donkey serum dissolved in 0.1 M phosphate buffered saline (PBS) and 0.3% TritonX-100 to prevent non-specific binding of IgGs. Sections were then incubated overnight at 4°C with primary antibodies. Goat anti-mouse (Chemicon, No. AP124B) or donkey anti-goat (Vectastain ABC kit, Vector, No. PK6105) or donkey anti-rabbit (Vectastain ABC kit, Vector, No. PK6101) biotynilated secondary antibody was used with a biotin-streptavidin immunostaining kit employing diamino benzidine (DAB) as a chromogen (Vectastaine Elite kit, Vector Laboratories). Further details are reported in a previous paper of our group.[20]

Control sections were processed as above, but using a non-immune IgG instead of the primary antibody. No positive reaction was observed under these conditions.

Counting and morphometry

For each slide, analysis was performed on 5 randomly chosen thymus lobules.

Thymus lobules were subdivided into the subcapsular, septa, cortex, cortico-medullary junction and medulla regions. For each region, three sampling fields of analysis (each field=150.0×10^3 μm^2) were randomly chosen and for each of them the nerve fiber branching area was detected by microscope connected to digital camera, using image analysis computer software (Qwin, Leica). The nerve branching is characterised by heterogeneous thicknesses, therefore in image analysis the digitalised measurements of the nerve fiber branching areas reliably avoid variance among samples.

Data were collected and reported as numbers expressing the area of nerve branching in the field of analysis (=150.0×10^3 μm^2).

Neural plexuses enveloped along intra-parenchymal arteries were specifically investigated along their course into the subcapsular zone, septa, cortex and medulla.

Fiber positive nerves, in accordance with Bodian's protocol, were analysed under microscope in a light field, while a fluorescence microscope was employed for other fluorescence techniques.

Data analysis

Data are presented as mean ± S.E.M. calculated from values detected in the individual animals of each experimental group. The normal distribution of data was assessed by means of the Kolgomorov-Smirnov test. Statistical differences among experimental groups for each lobular region investigated

were then assessed by two-way ANOVA, with the different experimental groups as the first source of variance, and the different techniques evidencing the nerve fibre component as the second one; the Newman-Keuls post hoc test was performed. Statistical procedures were performed with the Prism 2.01 statistical software (GraphPad Software Inc., CA, U.S.A.).

Results

Nerve fibers distribution

Quantitative results of nerve fiber distribution in thymus vessels and parenchyma of the lobular subcapsular region are summarised in Figure 1. In the *subcapsular region* of the thymus, the nerve fibers of sham-operated rats displayed wide intense branching along perivascular sites, with a smaller number of fibers branching in the parenchyma (Figure 2).

The rats subjected to chemical or surgical sympathectomy had a strong decrease of nerve fibers localized in perivascular sites, in comparison with the sham-operated ones, while intraparenchymal fibers were not affected by specific denervation (Figures 1 and 2). Instead, in rats subjected to total or partial parasympathectomy, we observed a moderate or very moderate decrease respectively in perivascular fibers only, and again, intraparenchymal fibers were not affected by parasympathectomy. In rats subjected to somatic nerve axotomy, we detected the disappearance of intraparenchymal fibers only, while perivascular fibers were not affected (Figures 1 and 2). Collecting all the morphometric data obtained by specific nerve cutting and the Bodian technique, we observed that sympathetic, parasympathetic and somatic nerves had a distribution of 60%, 30% and 10% of total nerve fibers, respectively.

Histochemical techniques in the *subcapsular region* of sham-operated rats identified cathecolaminergic nerve fibers in perivascular sites only, while histochemical cholinergic nerve fiber visualization revealed vascular and parenchymal presence of these fibers (Figure 3). The application of histochemical techniques following specific denervation confirmed the findings above detailed: cholinergic parenchymal branches disappeared after phrenic nerve cutting (Figures 1 and 3E), while vagus and laryngeal nerve cutting indicated that the vascular branches belong to the parasympathetic nerve system (Figure 1). After phrenic nerve cutting, we observed no variation in perivascular, cholinergic, or catecholaminergic histofluorescence (Figure 1). These findings indicate that in the subcapsular region, the parenchymal cholinergic fibers
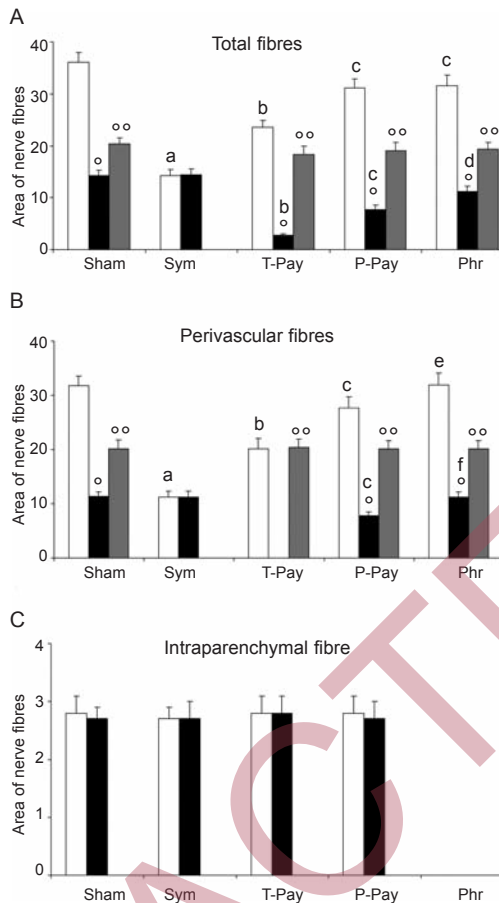

Figure 1. Analysis of thymus lobular subcapsular region. Bar graph showing morphometric analysis of nerve fibers running along vessels and branching into the parenchyma. Data are reported as Area of nerve fibers $\times 10^3$ μm^2, evaluated on standard field of analysis (see Materials and Methods section). White bar: Bodian's method positive nerve fibers (p.f.); Black bar: AChE p.f.; Grey bar: cathecolaminergic p.f.. Sym: Sympathectomised experimental group; T-Psy: Total Parasympathectomised experimental group; P-Psy: Partial Parasympathectomised experimental group; Phr: phrenectom-ised experimental group. Statistical significance between data related to experimental groups: a=P<0.05 *vs* sham group; b=P<0.05 *vs* sham and sympathectomy groups; c=P<0.05 *vs* sham, sympathectomy and total parasympathectomy groups; d=P<0.05 *vs* sham, sympathectomy, total and partial parasympathectomy groups; e=P<0.05 *vs* sympathectomy, total and partial parasympathectomy groups; f=P<0.05 *vs* total and partial parasympathectomy groups. Statistical significance between data obtained by different techniques used, in the same experimental group: °=P<0.05 *vs* Bodian p.f.; °°=P<0.05 *vs* AChE and Cathecol p.f.
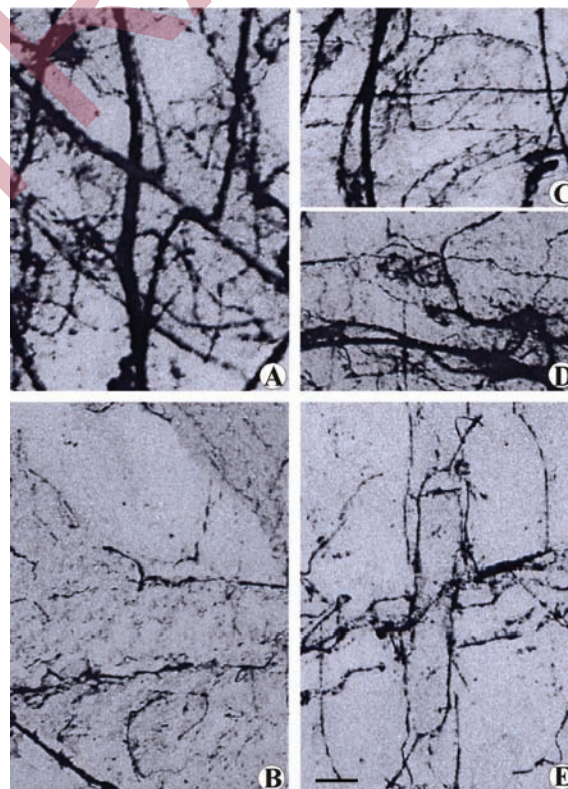

Figure 2. Microphotograph panel of nerve fibers in the subcapsular region of thymus. Bodian's method. Note the different distribution of nerve fibers according to the different nerve cuttings performed. (A) Sham-operated rat; (B) Surgical sympathectomized rats; (C) Phrenectomised rat; D: Partial parasympathectomised rat (laryngeal nerve cutting); E: Total parasympathectomized rat (nerve vagus cutting). Calibration bar: (A,B,E)= 40 μm; (C,D)= 60 μm.

belong exclusively to phrenic nerve branching.

Quantitative results of nerve fiber distribution in thymus vessels and parenchyma of several lobular regions are summarised in Figure 4.

In the *septal region* no nerve branching was observed in the parenchyma; instead, it seems that all fibers detected contribute to forming plexuses along vessel walls. In rats subjected to sympathectomy or total parasympatectomy we detected a reduction of 60% and 40% of total fibers respectively, compared with sham-operated rats (Figure 4). The histochemical visualization revealed that all sympathetic fibers were cathecolaminergic, while the parasympathetic fibers were cholinergic. In rats subjected to partial parasympatehctomy, we detected only a moderate reduction in cholinergic fibers. No evidence was observed in animals subjected to phrenic nerve axotomy (*data not shown*).

In the *deep cortical region, cortico-medullary junction (CM-j) and medulla,* the nerve fibers were observed branching along perivascular sites, except for a few fibers leaving perivascular sites, branching into the parenchyma.

In rats subjected to specific denervation, the results were similar to the ones observed in the septal region. The sympathectomy and

total parasympathectomy decreased the nerve fibers by 60% and 40% respectively, compared with sham-operated rats, in both perivascular fibers and parenchymal fibers (Figure 4). The histochemical visualization confirmed that all the sympathetic fibers were cathecolaminergic, while the parasympathetic fibers were cholinergic (*data not shown*).

In particular, in these regions, after denervation and histochemical techniques, the absolute number of nerve fibers branching into parenchyma was similar to the sympathetic catecholaminergic and parasympathetic cholinergic fibers detected. In terms of relative distribution between vessels and parenchyma, the presence of parasympathetic cholinergic fibers was instead slightly greater in the parenchyma, when compared with the relative distribution of sympathetic catecholaminergic nerve fibers (Figure 4). Furthermore, the parasympathetic cholinergic parenchymal branching was more widespread in the deep cortex region than in the other regions.

Microanatomical localization of dopamine markers

The cortico-medullary junction and medulla

were the thymus areas with the greatest dopaminergic expression.

Dopamine immunoreactivity was observed in the CM-j and in the medulla, whereas no immune reaction was observed in subcapsular, septal or deep cortex region. In the immunoreactive areas, dopamine displayed reticular localization (Figure 5A). No DAT immunoreactivity was noticeable in the thymic cortex, whereas immune reaction was observed in medulla and in CM-j. At higher magnification, immune reaction showed reticular localization (Figure 5C). No variation was observed following total or partial parasympathectomy or phrenic nerve cutting, while after chemical or surgical sympathectomy neither dopamine nor DAT immune reaction was observed again (Figure 5B, D).

Dopamine D1 and D2 receptor immunoreactivity was observed in the CM-j region to a slighter extent in the medulla, whereas no immune reaction was observed in subcapsular, septal or deep cortex regions (Figure 6).

Several thymus denervation protocols did not change the D1 and D2 receptor immunoreactivity pattern observed in non-denervated rats (*data not shown*).
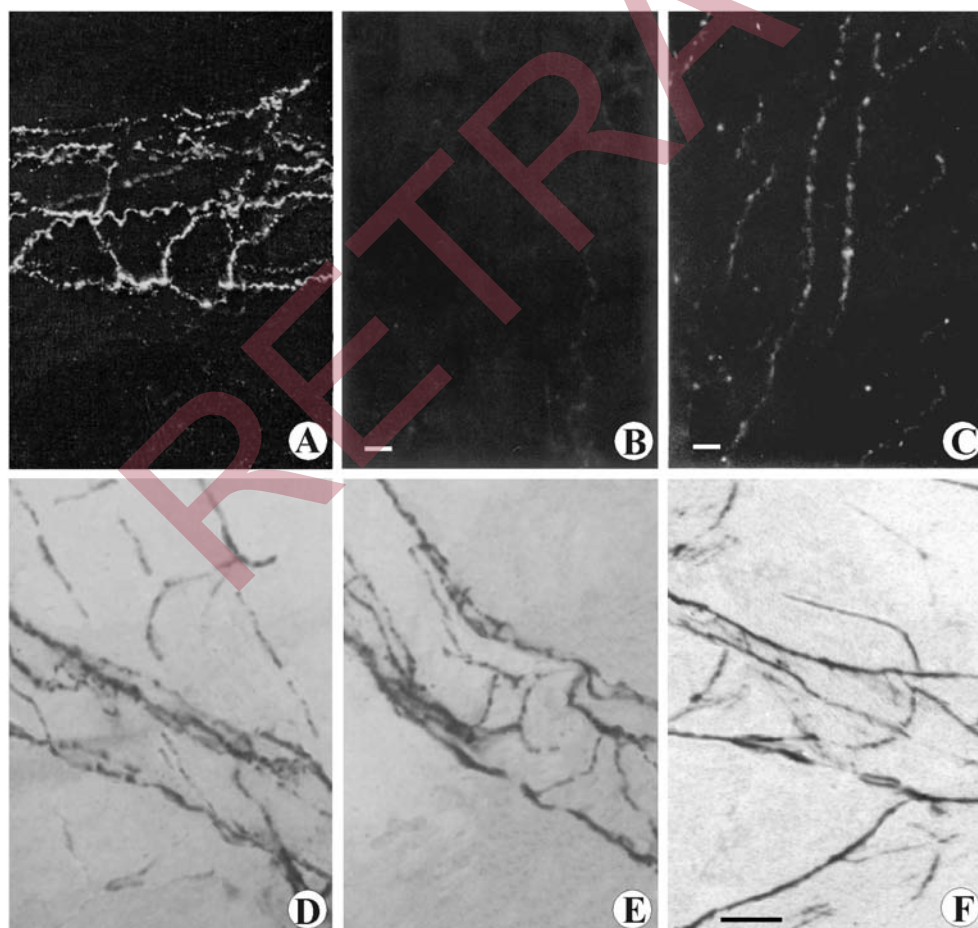

Figure 3. Microphotograph panel showing cathecolaminergic fluorescent nerve fibers (A,B,C) and histoenzymatic AChE positive nerve fibers (D,E,F). A: Sham-operated rat, subcapsular ragion. Note the exclusive distribution of fibers forming a rich perivascular plexus. B: Surgical sympathectomised rat, subcapsular region. Note the absence of cathecolaminergic fluorescent nerve fibers. C: Sham-operated rat, medulla. Note the distribution of parallel nerve fibers running along vascular profile and several branching fibers running into parenchyma. D: Sham-operated rat, subcapsular ragion. Note the distribution of positive nerve fibers running along vessels and branching into parenchyma. E: Phrenectomised rat, subcapsular region. Note the absence of parenchymal fibers, while the AChE perivascular plexus remain well observable. F: Phrenic denerved rat, medulla. Note the occurrence of positive nerve fibers (parasympathetic fibers) running along vessels and branching into parenchyma. Calibration bar: 45 μm.

Discussion

Several findings indicate the occurrence of branching of the somatic phrenic nerve, vagus and sympathetic nerves into the thymus.[2,34] Although a more specific immunohistochemistry technique currently provides fine visualization of nerve profiles, the use of the Bodian technique together with other techniques is useful in visualizing intricate intraparenchymal nerve branching development and its quantitative depletion after denervation experiments. There are no fibrillary components of thymus parenchyma that cause aspecific reactions and limit Bodian technique specificity in marking nerve fibers.[17,31,33]

Thymus innervation by the phrenic nerve is an old acquisition from embriogenic[4] and anatomical studies.[5] This finding about thymus anatomy is reported in several texts and treatises.[35-37] Nevertheless, we have not been able to find further studies about intraparenchymal phrenic nerve thymus innervations in the literature.

In the present work, the intraparenchymal branching of the phrenic nerve has been visualized, following specific denervation, as an AChE-positive nerve component exclusively distributed in the intraparenchymal subcapsular region of thymus lobules. Unlike other intraparenchymal nerve components, the phrenic nerve does not participate to form the perivascular plexus as the access way of nerve fibers. The phrenic nerve seems to access the intraparenchymal subcapsular region directly through the connectival capsule of thymus lobules. These findings agree well with the
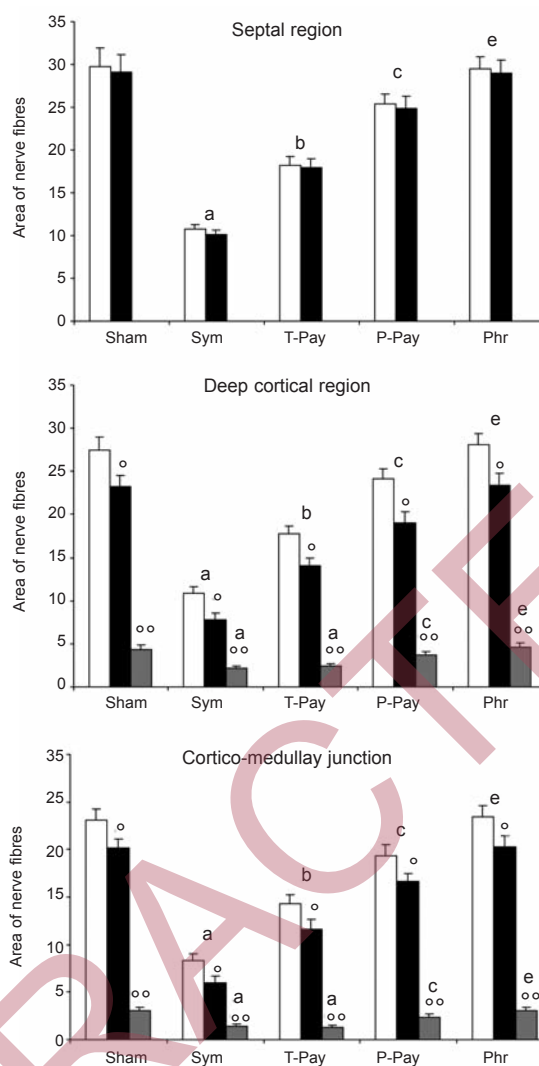
Figure 4. Analysis of regions in which thymus lobule has been subdivided (see Materials and Methods section for detail). Bar graph showing morphometric analysis of nerve fibers running along vessels and branching into the parenchyma. Data are reported as Figure 1. White bar: total nerve fibers; Black bar: perivascular fibers; Grey bar: intraparenchymal fibers. Legend of statistical significance as in Figure 1.
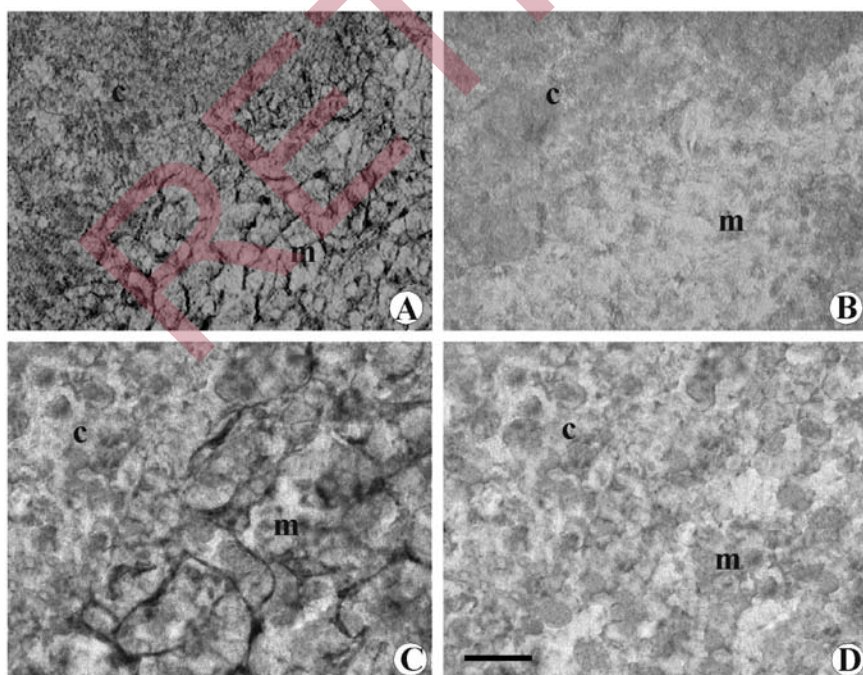
Figure 5. Microphotograph panel of immunohistochemistry evidence of dopamine (A,B) and DAT (C,D) presence into thymus. A: Sham-operated rat. Note the occurring of positive dopamine immunohistochemistry into medullary parenchyma. B: Chemical sympathectomised rat. Note the absence of dopamine immunohistochemistry reaction. C: Sham-operated rat. Note the occurrence of positive DAT immunohistochemistry fibers into medullary parenchyma. D: Chemical sympathectomised rat. Note the absence of DAT positive reaction. c: deep cortical region; m= medulla. Calibration bar: 50 μm.
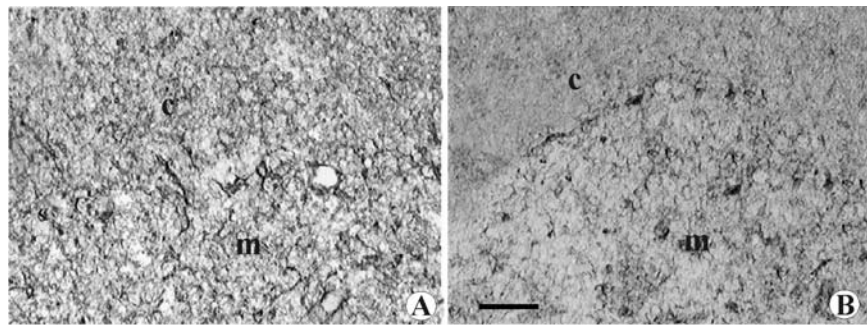
Figure 6. Microphotograph panel of immunohistochemistry evidence of D1 dopamine receptor (A) and D2 dopamine receptor (B) presence in the thymus. Legends as in Figure 5. c: deep cortical region; CM-j= cortico-medullary junction; m= medulla. Calibration bar: 50 μm.

embryonal origin of subcapsular thymic epithelial cells.[4,38] Indeed, Mićić and colleagues[10] have found AChE positive nerve profiles in the subcapsulary region mainly in close proximity to the thymic epithelial cells. These findings have stimulated further evaluation of the functional involvement of the phrenic nerve in the cortico-lympho-epitelial complex, in which thymic epithelial cells interact with immature lymphocytes (CD4⁻ and CD8⁻, double negative, thymocytes).[39]

Vagus nerve thymus innervation is another widely questioned and important point.[8] In effect, the mass of evidence about parasympathic innervation of the thymus is based on the findings of an AChE positive nerve fiber profile in the thymus[7,10,23] and on the influence of cholinergic pathways in thymus function,[14,15] but their belonging to effective vagal branching is questioned.[8,19]

Some findings about direct thymus innervation and influences by vagus nerve have been reported.[5,11,40] Nevertheless, mapping of brain vagal nuclei is still uncertain. In fact, some authors reported the presence of brainstem nuclei that give rise to efferent vagal fibers that reach the thymus gland,[16,41,42] but other studies did not detect them.[9] Indeed, Trotter and his collaborator[9] excluded from their study animals that showed labelling neurons in *Nucleus Tractus Solitarii* and *Nucleus Ambiguus* because the authors considered these findings an indication of tracer (pseudorabies virus) leakage from the thymus to the esophagus.

To avoid these difficulties, we used AChE and cathecolamine histochemistry associated with specific denervation experiments, so as to investigate the organization of sympathetic and parasympathetic thymus nerve fibers in their specific running and branching.

We have observed in rats subjected to specific denervation the disappearance of the sympathetic and parasympathetic fibers that penetrate into thymus parenchyma along vessels accompanying tissue connective septa (septal region). Few fibers of either system leave ves-

sel profiles to branch into parenchyma at deeper cortical region and lower region of thymus lobule. Many fibers of either systems remain to form plexuses along vessels branching into the medullary region. This organization may support the supposed involvement of the sympathetic and parasympathetic systems in the blood-thymic barrier and thymocyte trafficking as reported by other authors.[43,44]

Comparing the quantity of sympathetic and parasympathetic fibers, we have observed that there are proportionally more intraparenchymal fibers of the parasympathetic system than of the sympathetic one. The majority of the latter remain perivascular. These findings may support the hypothesis of Mićić and colleagues[10] that parasympathetic system is involved in the thymocyte maturation process.

Previous findings of other authors have indicated that the thymus dopaminergic system is related to the organization of the sympathetic nervous visceral system.[21,45,46]

DAT is an important marker indicating dopamine reuptake; it is normally expressed in cells involved in the use of the dopaminergic system.[47] In the present work, we observed that dopamine and DAT have similar immune reactive appearance and localization in thymus parenchyma, confirming the presence of the dopaminergic system in the thymus. Furthermore, our findings after specific nerve axotomy show that it cannot be excluded that the dopaminergic system is present in sympathetic nerve fibers.

The same authors have also posited nonsynaptic release of neurotransmitter by sympathetic fibers.[46] Indeed, neurotransmitter release diffusion in a paracrine fashion may explain the reticular appearance of dopamine immune reaction.

The occurrence of D1 and D2 receptor immune reaction in thymus medulla, not affected by denervation protocols, indicates the location of these dopamine receptors in sites different from nerve fibers. Resolution limitations imposed by the microanatomical techniques employed in this study made it

impossible to identify the cellular populations with dopamine concentrations significant enough to be measured. From a morphological point of view, these structures can correspond to processes of epithelial thymic cells as well as to thymocytes strictly close to these cellular processes. We have begun to clarify this crucial point through the use of cytofluorimetry.

To summarize, in the present work, the distribution of the dopaminergic system has been observed mainly in the thymus medulla where thymocytes have their last maturation steps. These findings may be related to observations of dopamine receptors on outer membrane of circulating lymphocytes,[24,25] suggesting that the dopaminergic system plays a functional role on thymocytes resident in the thymus medulla. Further experiments are underway to define the role of the dopaminergic system in the functional biology of thymocytes and mature lymphocytes.

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