

Imperial College
London

Neurological inflammatory disease

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Clinical Reader in Neuroimmunology

Outline of lecture

- Introduction
- Classification of neuroinflammatory disorders
- CNS inflammation: Multiple sclerosis
- Brief summary of related CNS inflammatory conditions
 - CNS-specific inflammatory syndromes
 - Acute disseminated encephalomyelitis
 - Neuromyelitis optica

The spectrum of neurological immune-mediated disorders

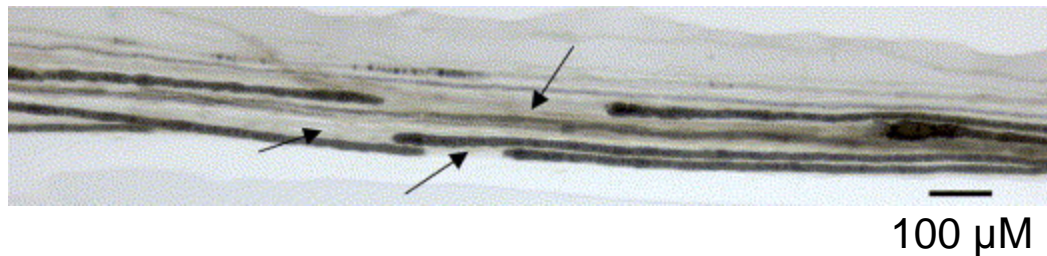
- Target anatomical sites:
 - Muscle and neuromuscular junction
 - Peripheral nervous system
 - Central nervous system
- *Cellular/Molecular targets:*
 - *PNS myelin, Schwann cells, axons*
 - *CNS myelin, oligodendrocytes, axons*
 - *Ligand- or Voltage-gated ion channels, water channels*

Disorders of muscle and neuromuscular junction

- Inflammatory myopathies
 - Idiopathic Polymyositis
 - Dermatomyositis
 - Inclusion body myositis
- Neuromuscular junction disorders
 - Myasthenia Gravis
 - Lambert-Eaton Myasthenic Syndrome

Peripheral nerve disorders

- Acquired demyelinating inflammatory neuropathies
 - Acute: Guillain-Barre' Syndrome
 - Chronic Inflammatory Demyelinating Polyneuropathy



Definition of CNS inflammatory disorders

- Virtually any type of acute injury to the CNS results in some degree of inflammation (e.g. infections, tumours, stroke)
- We consider ***neuro-inflammatory*** those conditions characterised **primarily** by inflammation
- Aetiologies are unknown or thought to be autoimmune

Main CNS inflammatory disorders

- **MS, neuromyelitis optica, ADEM, Sjogren's, neuro-SLE, Behcet's, sarcoidosis, anti phospholipid antibodies syndrome**
- **CNS vasculitides**

Multiple sclerosis: definition

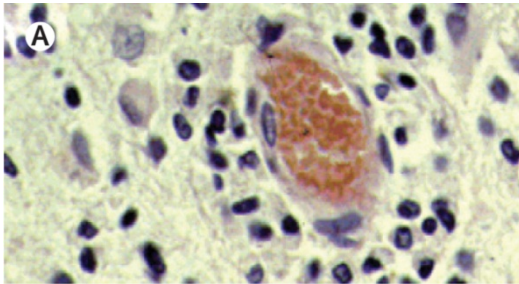
- A chronic inflammatory multifocal demyelinating disease of the central nervous system of unknown cause resulting in loss of myelin and oligodendroglial and axonal pathology
- Typically affecting young adults with exacerbating-remitting pattern or chronic progressive evolution

MS pathogenesis – the working hypothesis

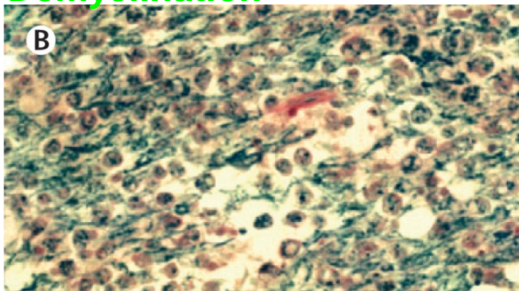
- MS is primarily considered an **inflammatory**, probably **autoimmune demyelinating** disease of the CNS
- A **neurodegenerative component** to the disease is increasingly recognised
- Exact cause of the pathological process remains unknown

Histopathology of MS – 3 main components

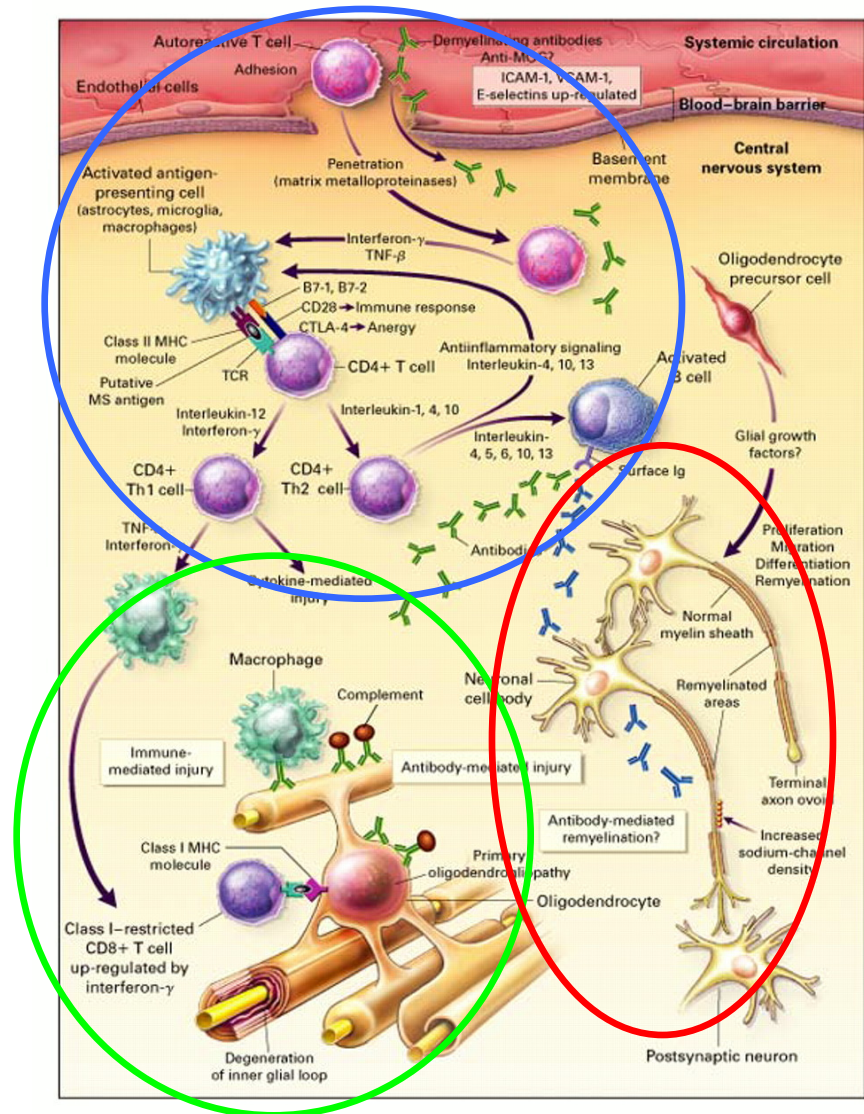
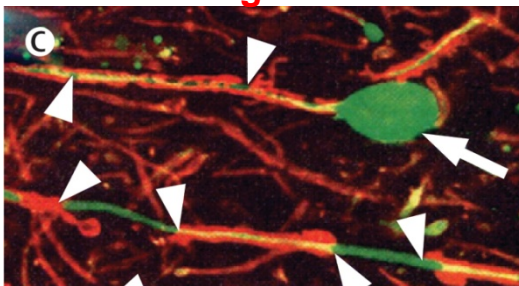
Inflammation



Demyelination



Axonal damage



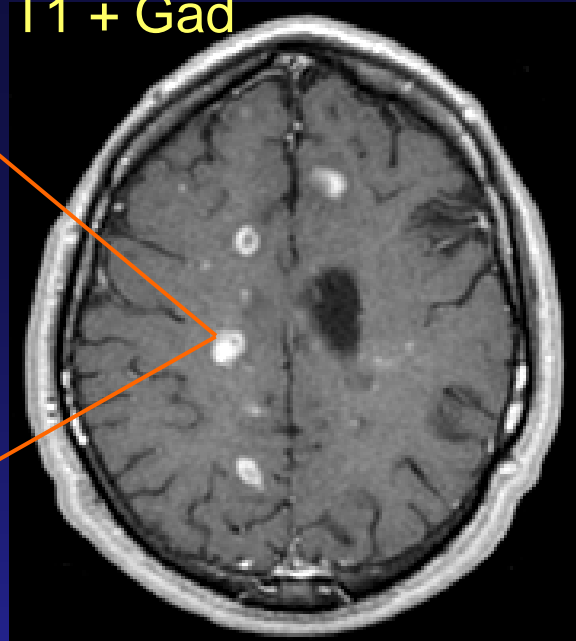
Inflammation and demyelination



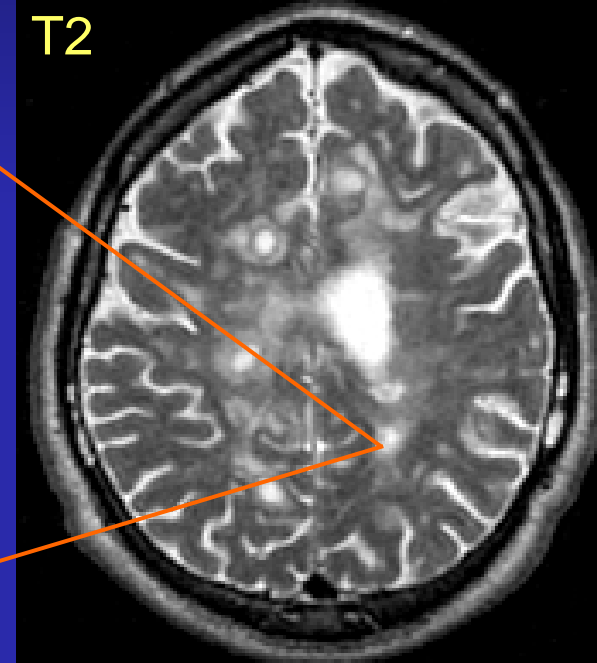
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MRI

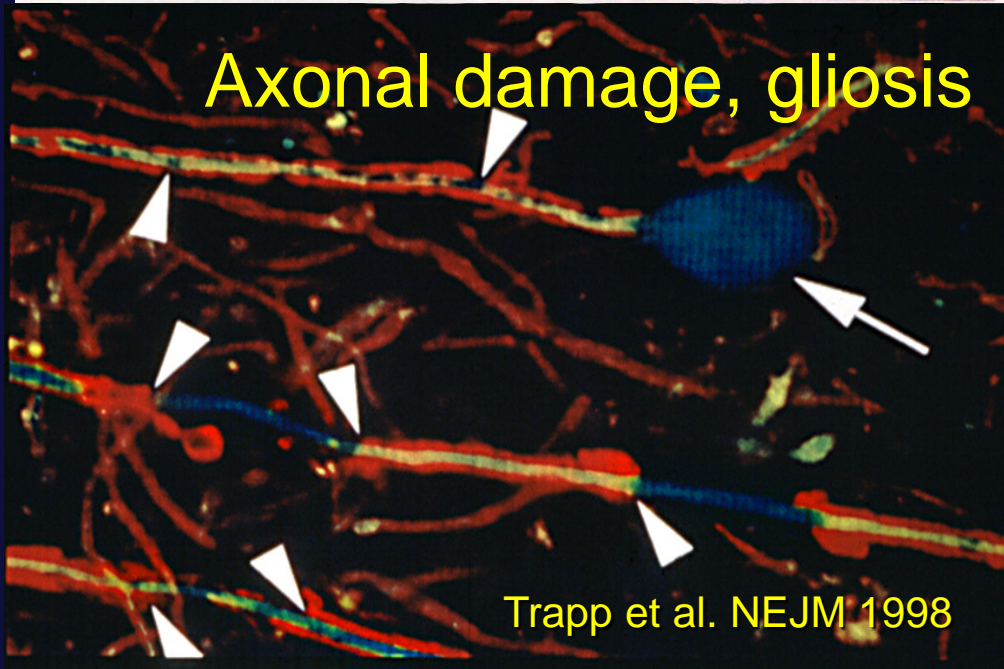
T1 + Gad



T2



Axonal damage, gliosis



Trapp et al. NEJM 1998

Basis of the autoimmune hypothesis in MS

- 1. Immunopathology of lesions**
- 2. Susceptibility associated with immune response genes**
- 3. CSF immunological abnormalities**
- 4. Subtle alteration of blood T cell functions**
- 5. Animal models of autoimmune disease**
- 6. Comorbidity and similarities with other autoimmune diseases**
- 7. Response to immuno-suppressive and -modulatory therapies**

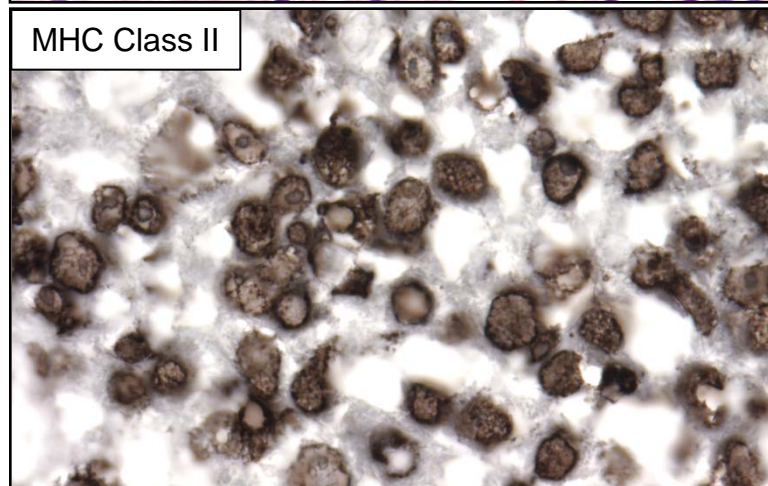
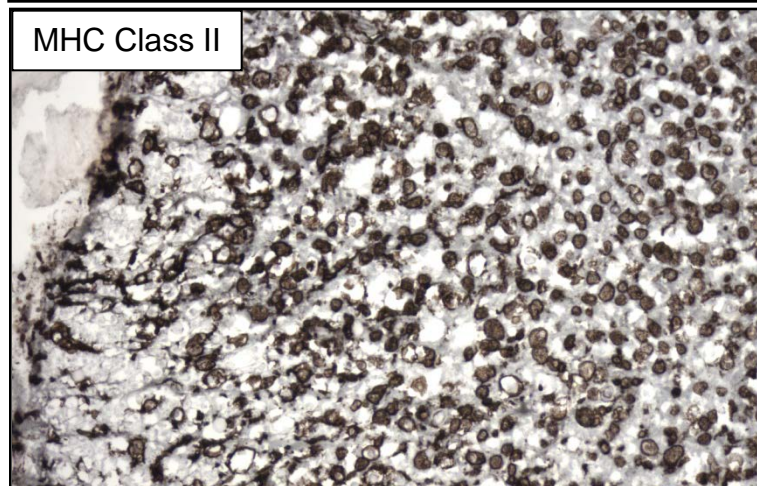
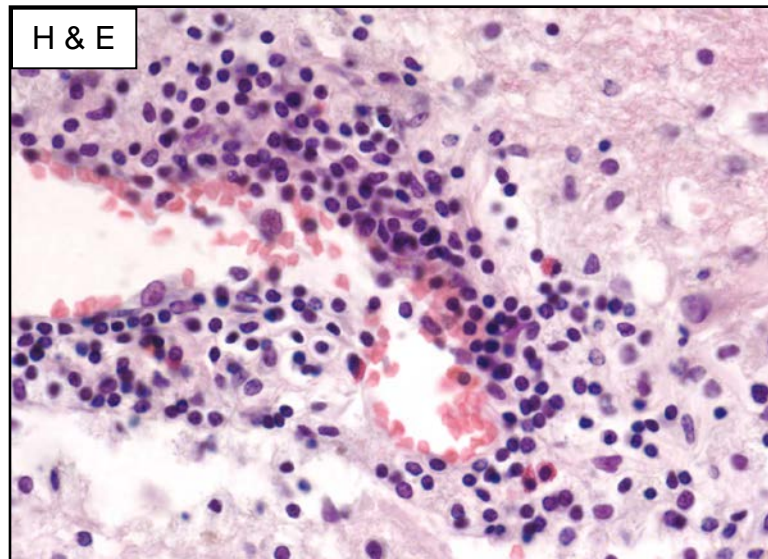
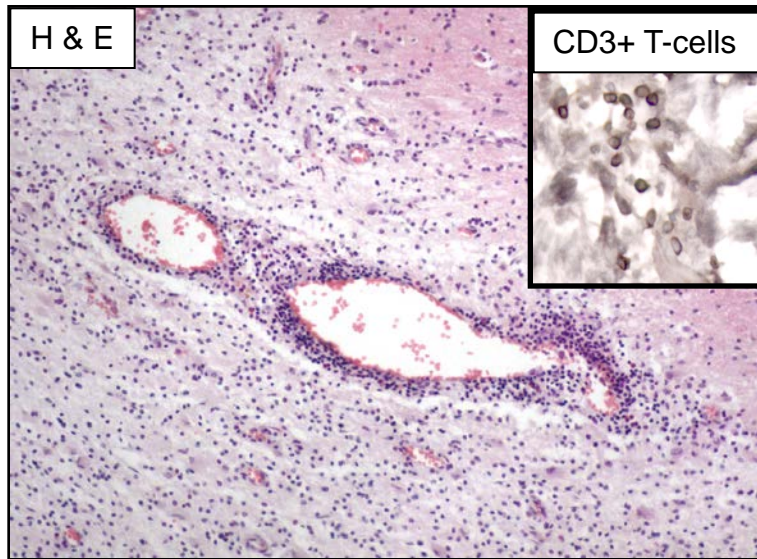
1. Immunopathology of CNS

Perivascular cuffs and intra-parenchymal infiltrates of inflammatory cells, mostly **CD4+** and **CD8+ T cells**

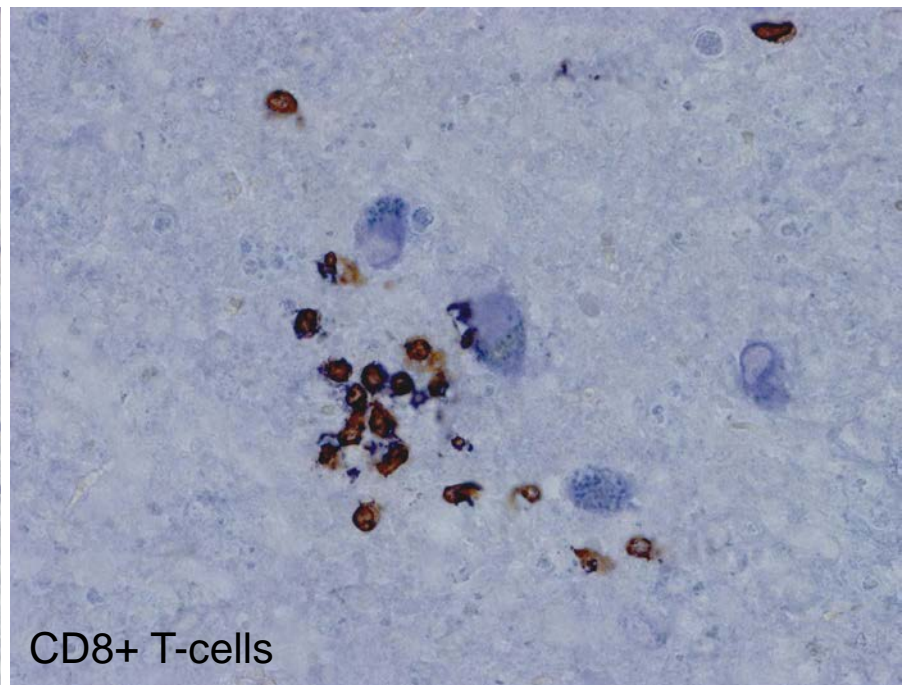
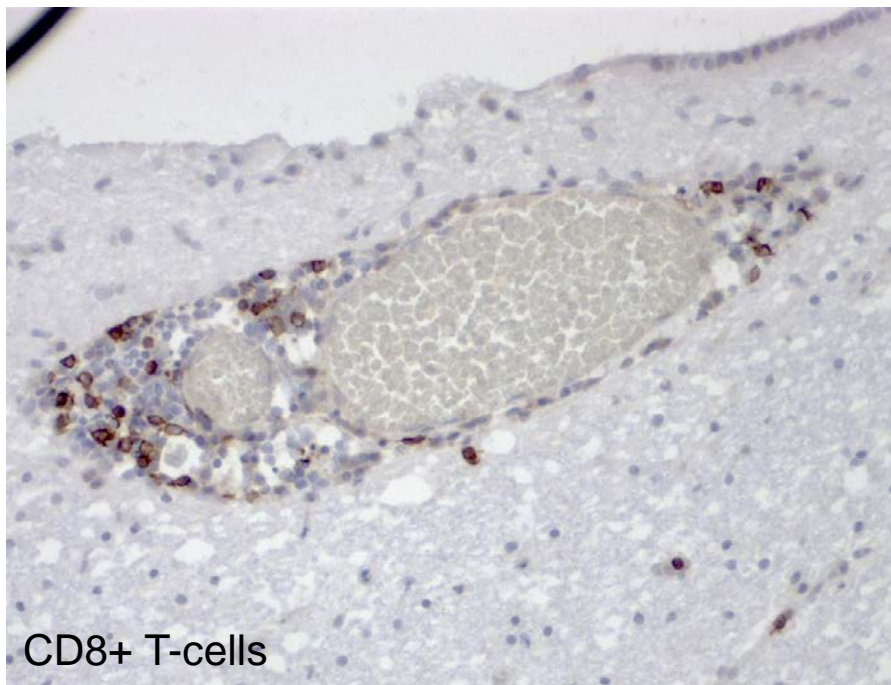
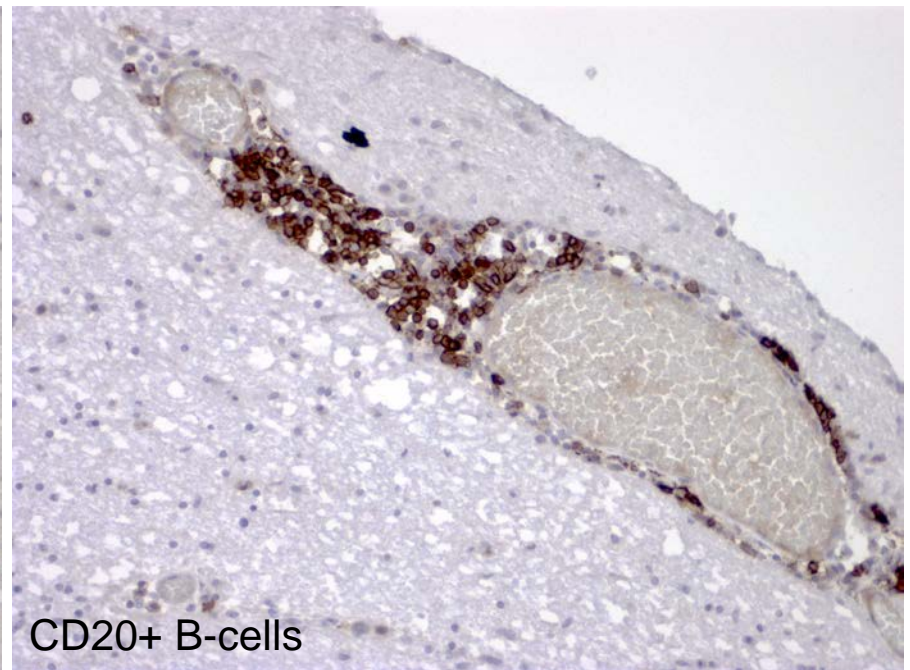
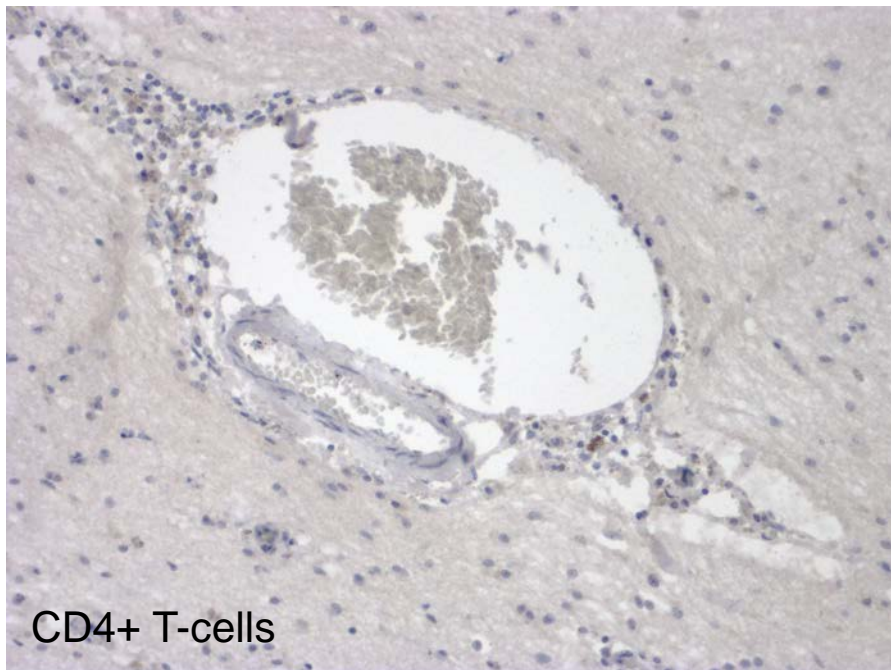
B-cells are found in perivascular and meningeal locations where they can aggregate or form part of ectopic lymphoid follicles

Myelin-laden **macrophages** in and around lesions

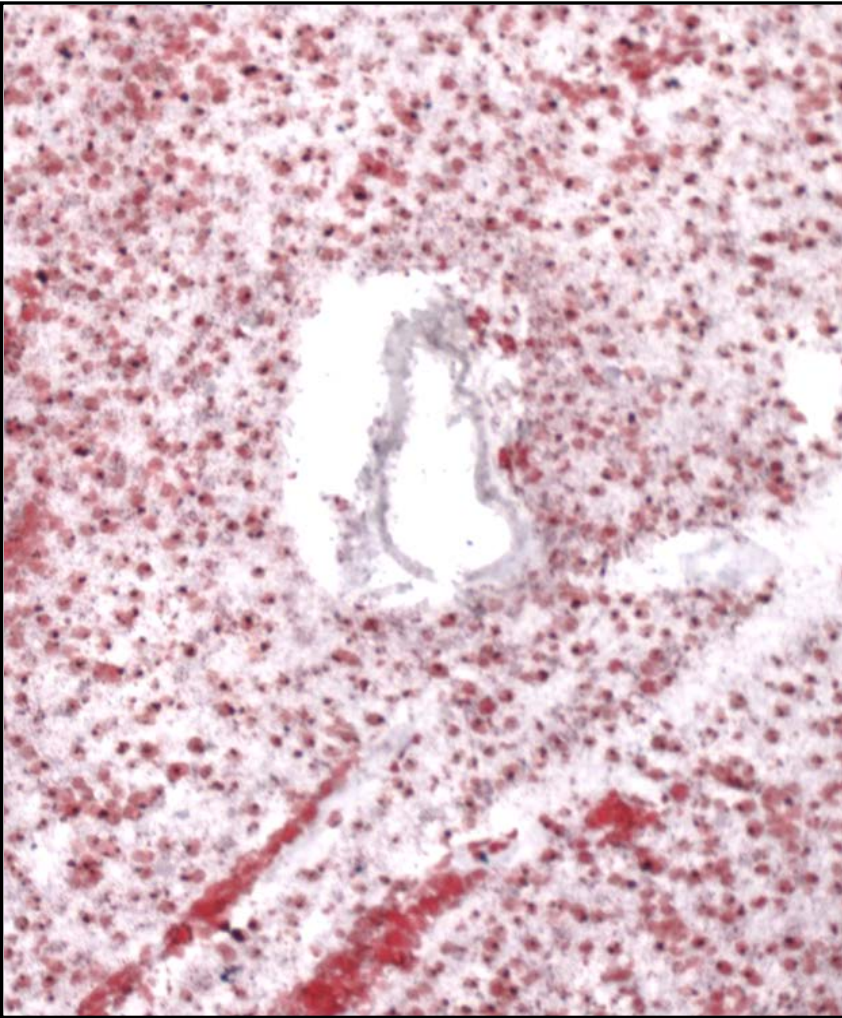
Inflammation and MS - the earliest events



T-lymphocyte infiltration is only seen during the very early stages of lesion formation and even during active demyelination (above) only few T-cells are found in the brain parenchyma. B-lymphocytes may also be found in small numbers. The majority of inflammatory cells in the MS lesion are monocytes/macrophages.



Macrophages and MS

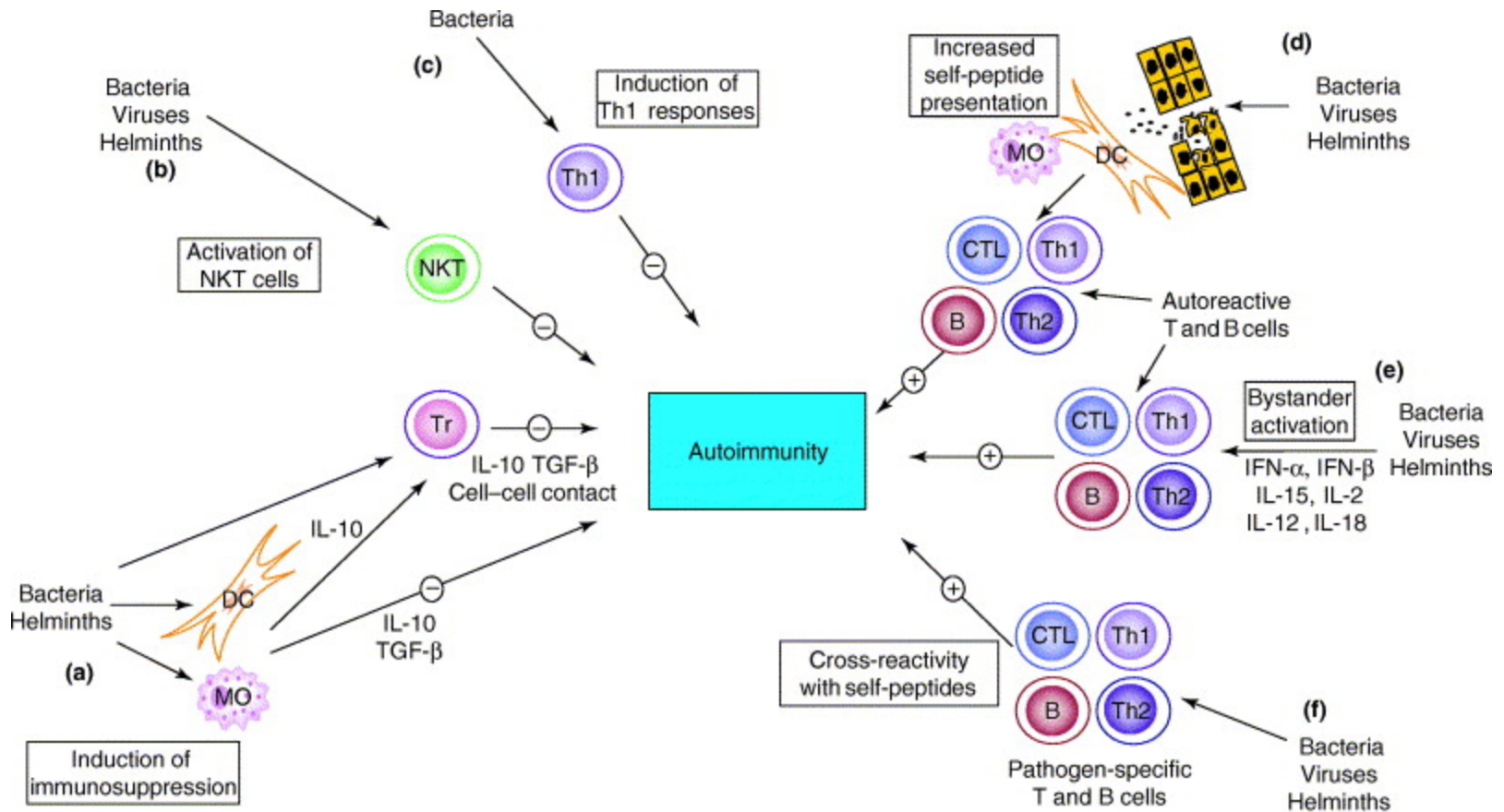


Macrophages in an active MS plaque. The foamy macrophages contain numerous lipid droplets, stained here with oil red-O, which represent myelin breakdown products

How do lymphocytes become activated?

- To migrate into tissues, including CNS, lymphocytes require activation
- **The events leading to pathological immune activation in MS are unclear**
- Possible mechanisms induce infection or cross-reactivity with microbial, especially viral antigen(s)
 - **Molecular mimicry**
 - **Bystander activation**

Potential mechanisms for how infections with pathogens might influence the development of autoimmunity

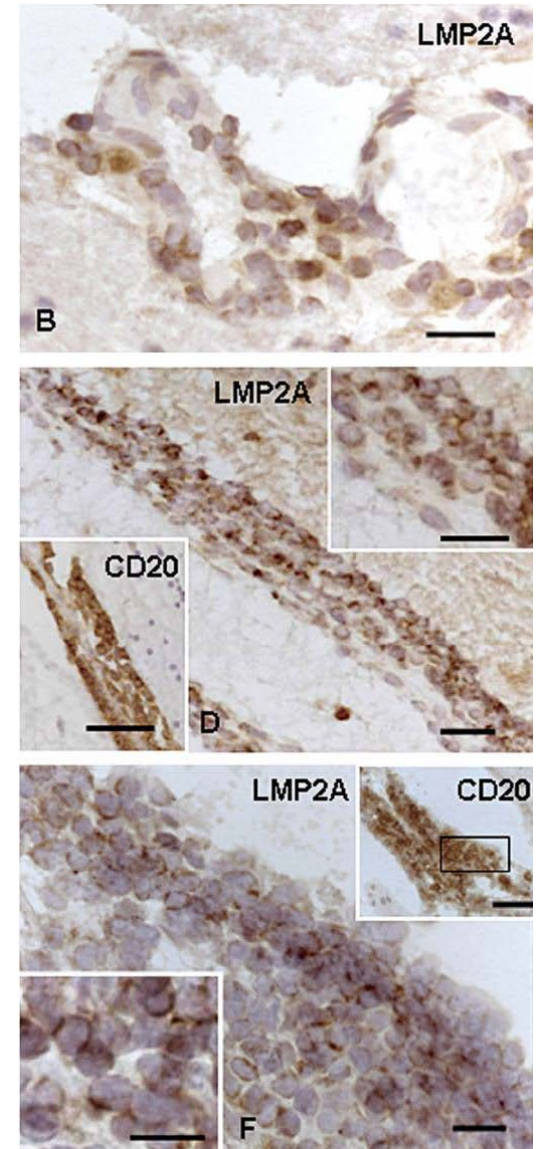


TRENDS in immunology

A possible role of EBV in MS pathogenesis:

1 – histological studies

- EBV almost exclusively infects B cells and uses the B-cell differentiation program to establish a persistent, usually asymptomatic, latent infection in humans.
- Using in situ hybridisation and immunohistochemistry, B cells infected with EBV were detected in post-mortem brain tissue (Serafini et al JEM 2007; JNEN 2010)
controversial



A possible role of EBV in MS pathogenesis:

2 – serological studies

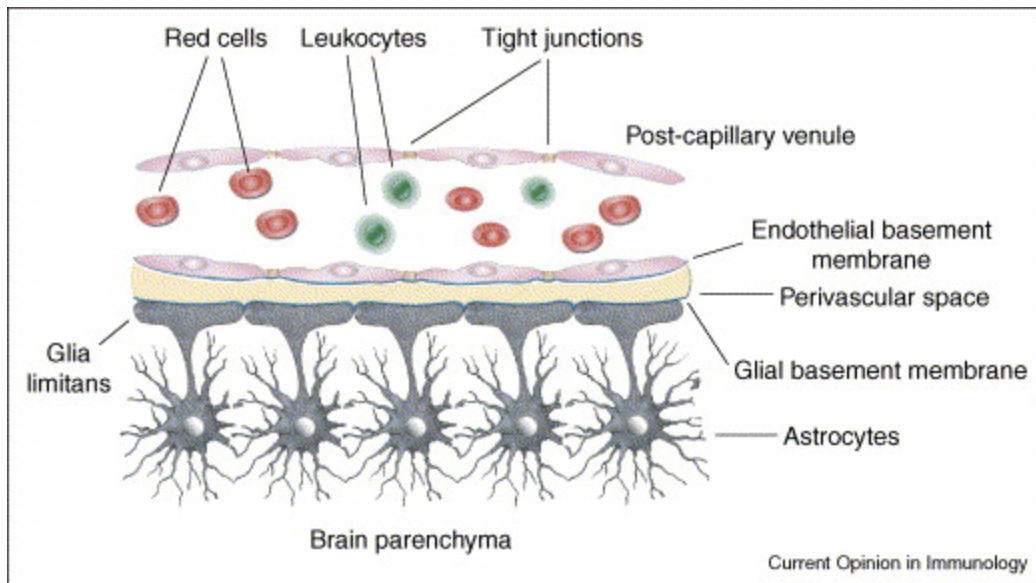
- Large serological studies show ~100% serological positivity for EBV infection in MS vs. 90% in healthy (Ascherio and Munch, *Epidemiology*. 11(2):220-224, March 2000)
- Odds ratio of MS comparing EBV seropositive individuals with EBV seronegative individuals was 13.5 (95% CI = 6.3–31.4)
- In longitudinally followed US military personnel, MS risk was 36-fold higher among individuals with anti-EBNA complex IgG titers ≥ 320 than among those with titers < 20 (Munger et al. *Multiple Sclerosis* 2011)

How do immune cells get to the CNS?

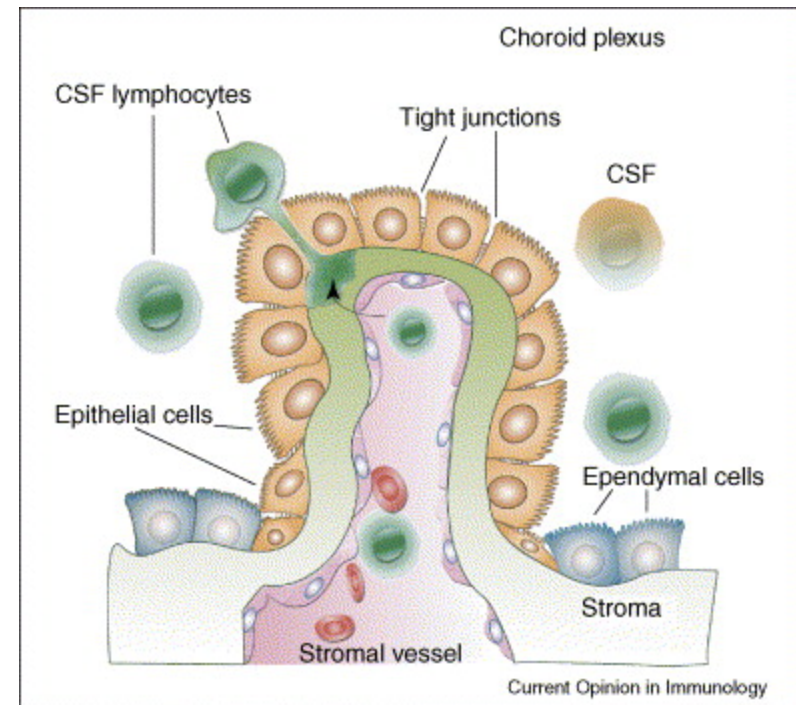
- The CNS is an immune privileged compartment, which is carefully shielded from potentially harmful immune reactions
- There is not a classic lymphatic drainage of the parenchyma
- To get to the CNS leukocytes must pass either of the two physiological barriers:
 1. **The Blood-Brain Barrier**
 2. **The Blood-CSF barrier**

Physiological barriers shielding the CNS

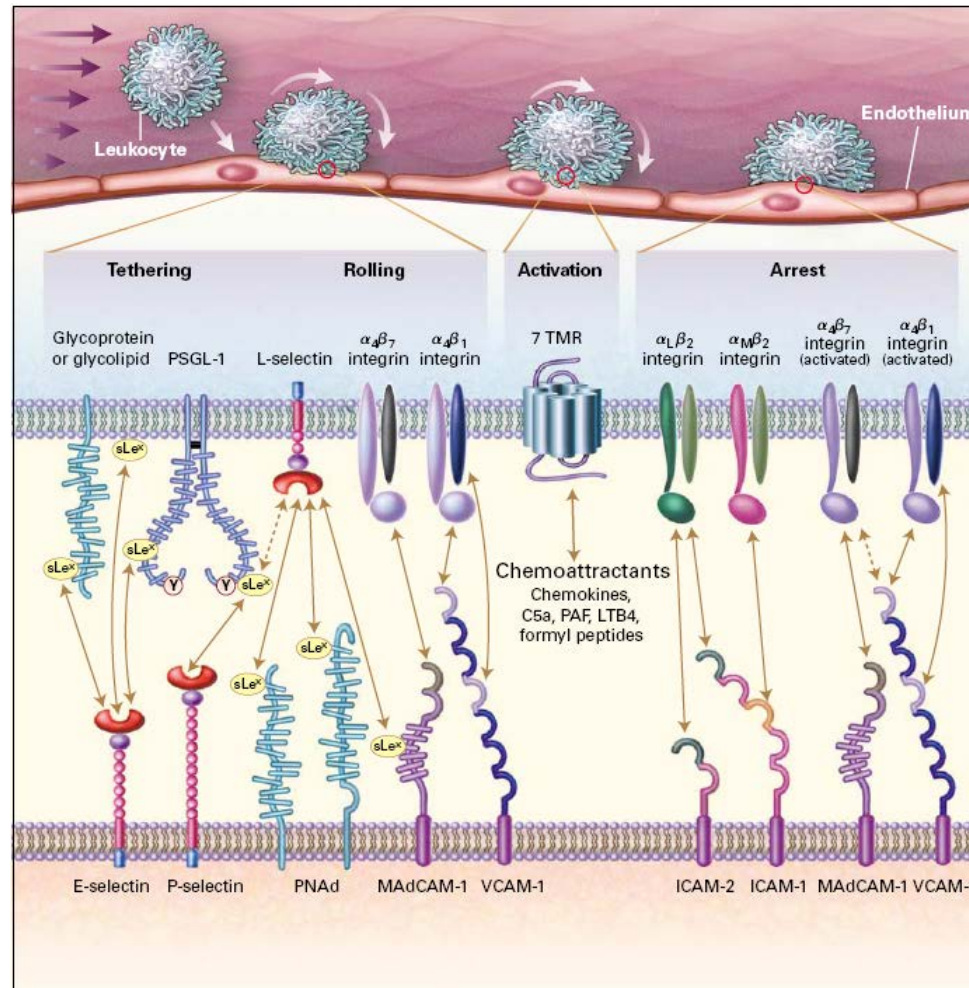
The Blood-Brain Barrier



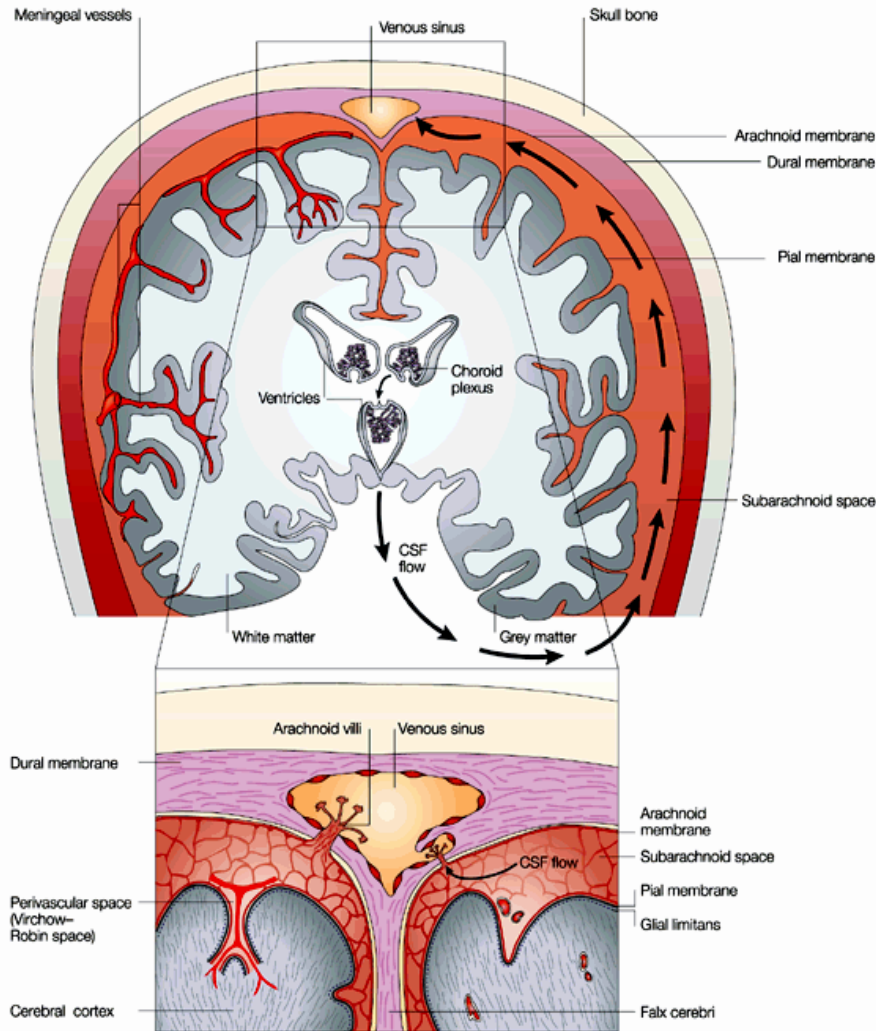
The Blood-CSF Barrier



Essential Molecular Players in the Multistep Adhesion Cascade.



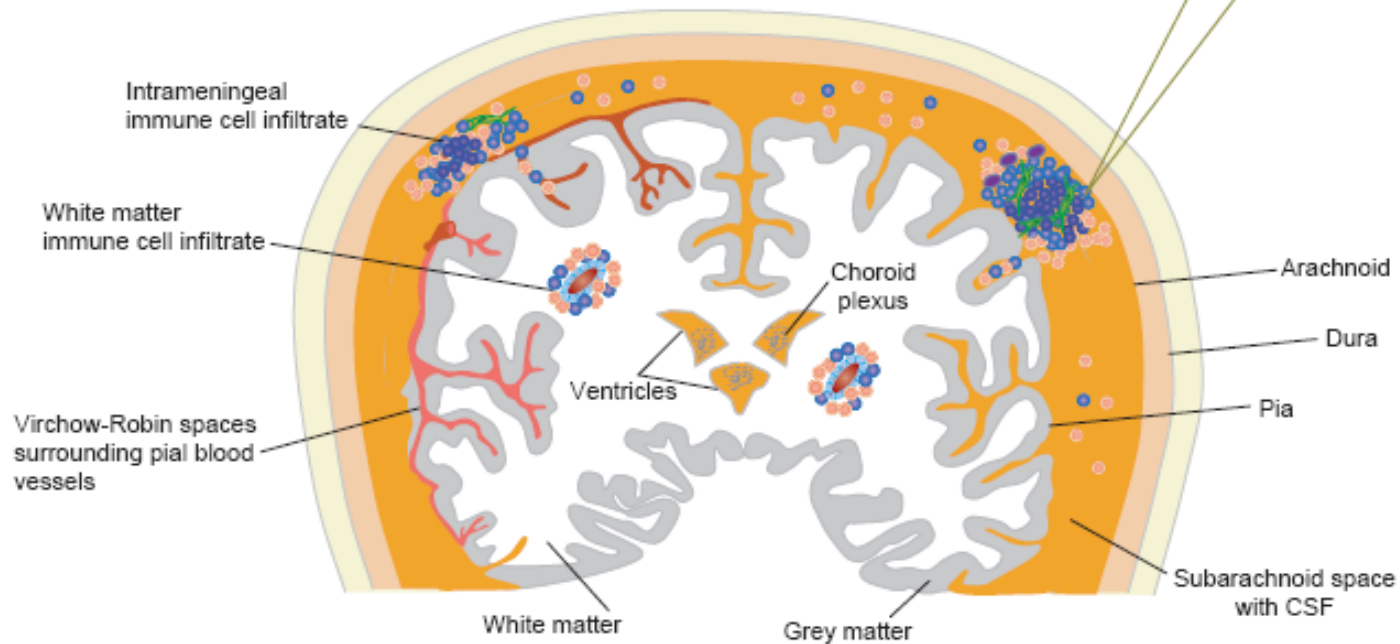
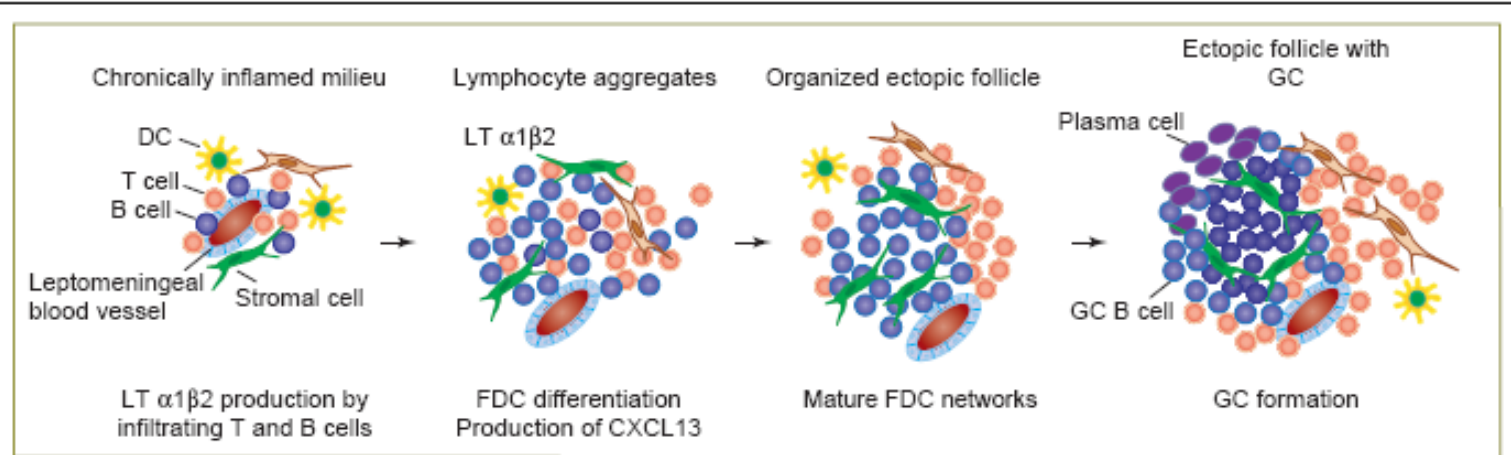
The blood-CSF route to the CNS



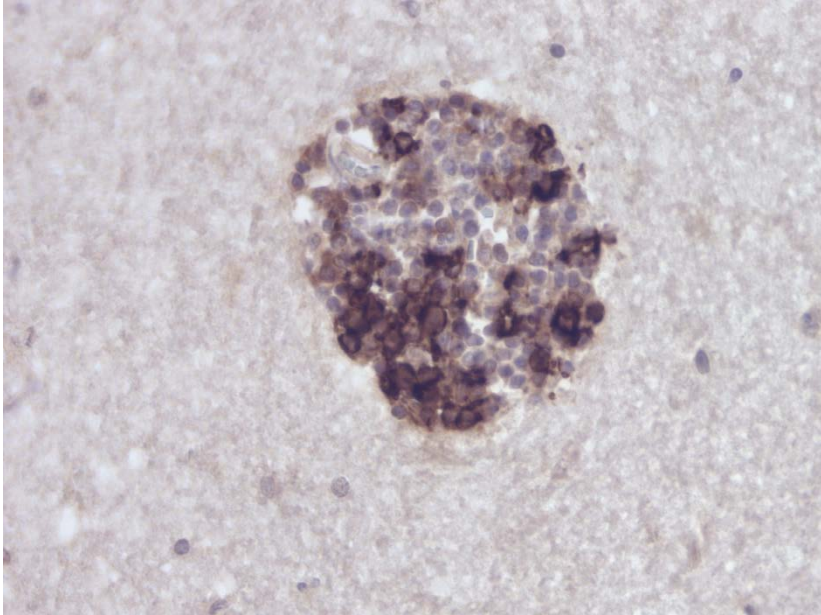
- Choroid plexus
- Subarachnoid space
- Pia
- Brain cortex



A role for B-cells in cortical pathology

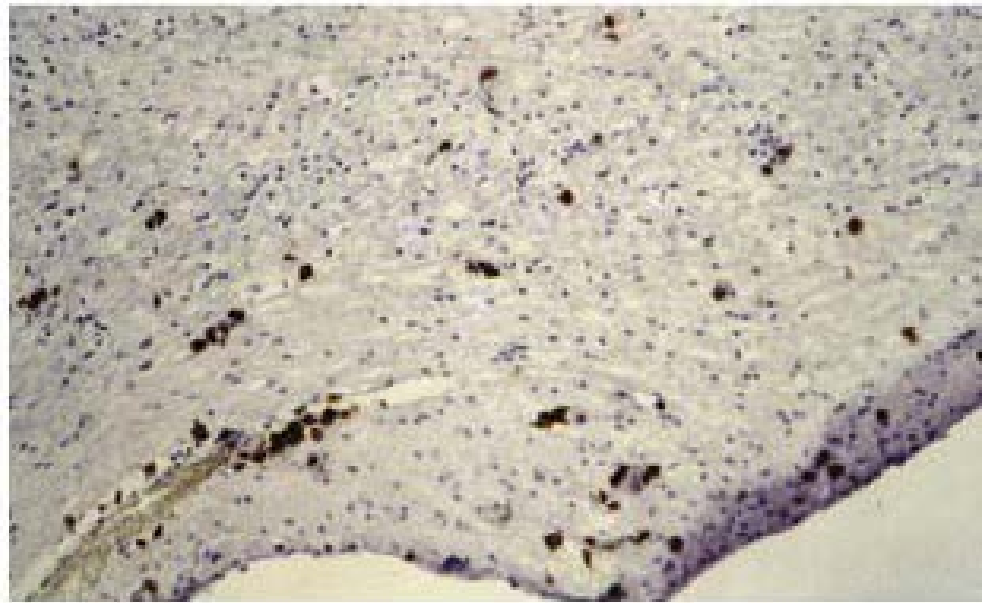
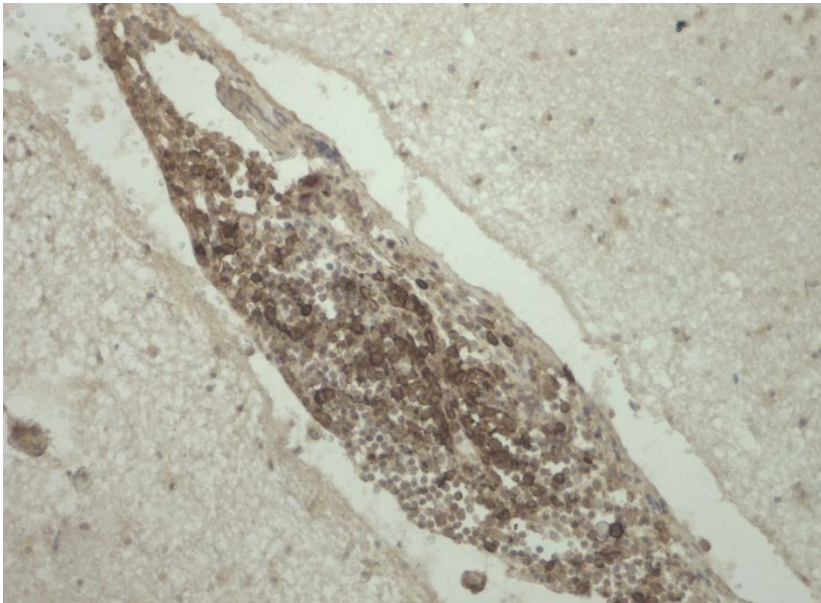


B-lymphocytes and plasma cells



B-cell follicles are found in perivascular and meningeal locations

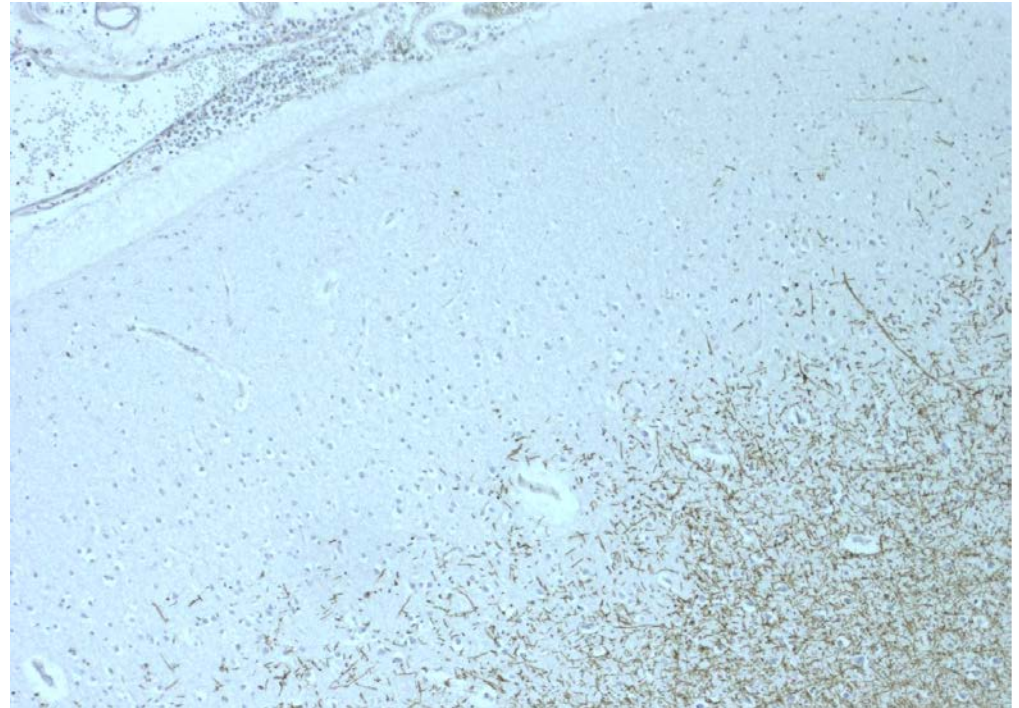
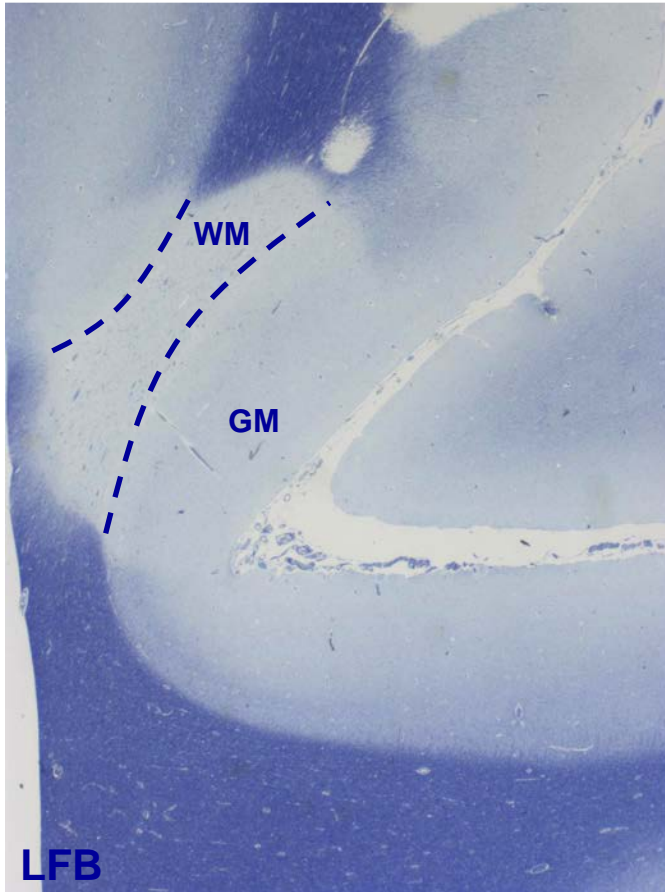
Isolated B-cells and plasma cells are found in the parenchyma in active lesions and in a perivascular location in chronic lesions



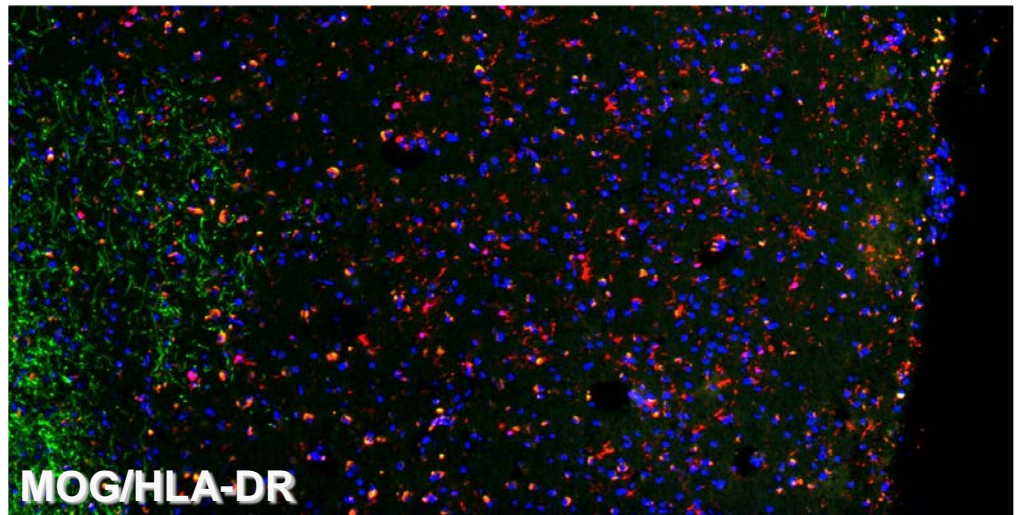
B cell involvement in MS

- In MS lesions (and CSF) there are clonally expanded B cells
- **Ectopic B cell follicles develop in meninges of patients with SP-MS**
- BAFF (B cell activating factor, also named BLyS), a member of the TNF family, is overexpressed in MS tissue (astrocytes)
- Subpial B cell follicles can restimulate inflammatory T and B cells
- Secretion of inflammatory mediators diffusing to the brain cortex

Pathology of grey matter lesions



Grey matter lesions are best identified using myelin protein immunostaining



MOG/HLA-DR

2. Susceptibility associated with immune response genes

- Whole genome scans in large populations have confirmed associations with immune genes, including:

HLA-class II (DRB1*1501, DRB5*0101; DQw6) strongest

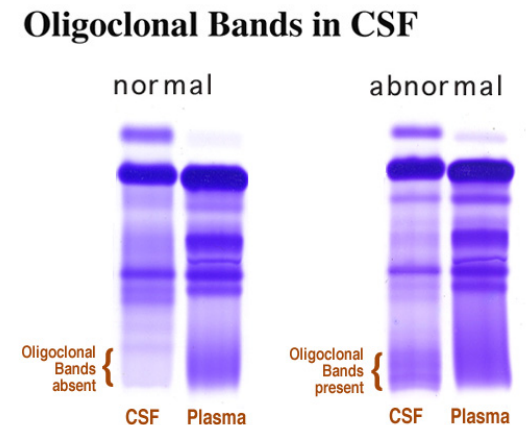
IL-7R

IL-2 R alpha

CD58

3. CSF immunological abnormalities

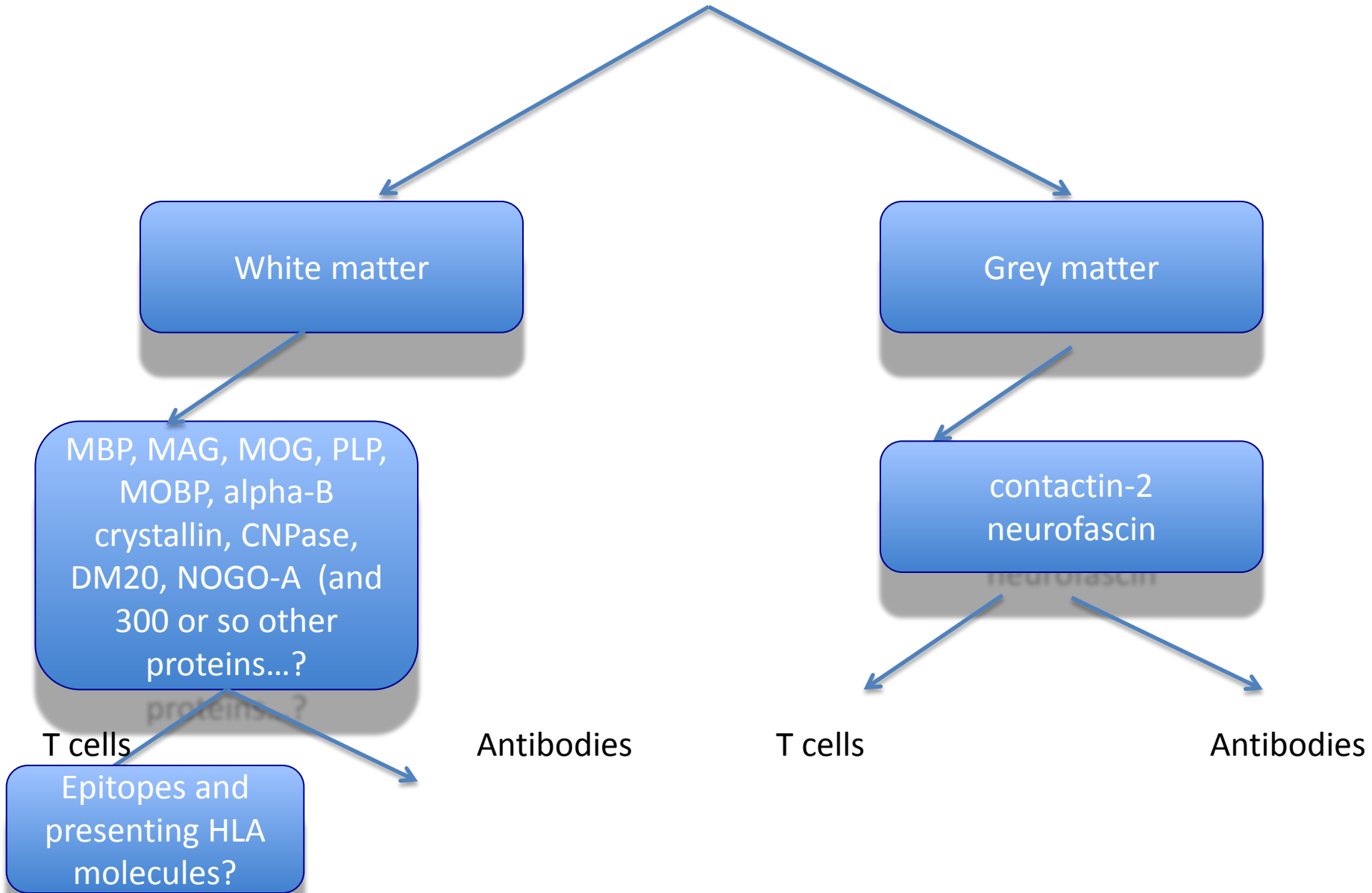
- Leukocyte counts can be normal but are often mildly increased above the normal of ≈ 3000 leukocytes/mL
- In MS 80% of total CSF cells are T cells (45% in blood), mainly memory T cells (up to 30% of CSF cells during inflammation), 5% are monocytes, $\leq 1\%$ B cells, plasma cells
- There can be a minor protein increase
- Increased production of IgG in the CNS
- CSF oligoclonal bands are very frequent detected in MS and stable over years



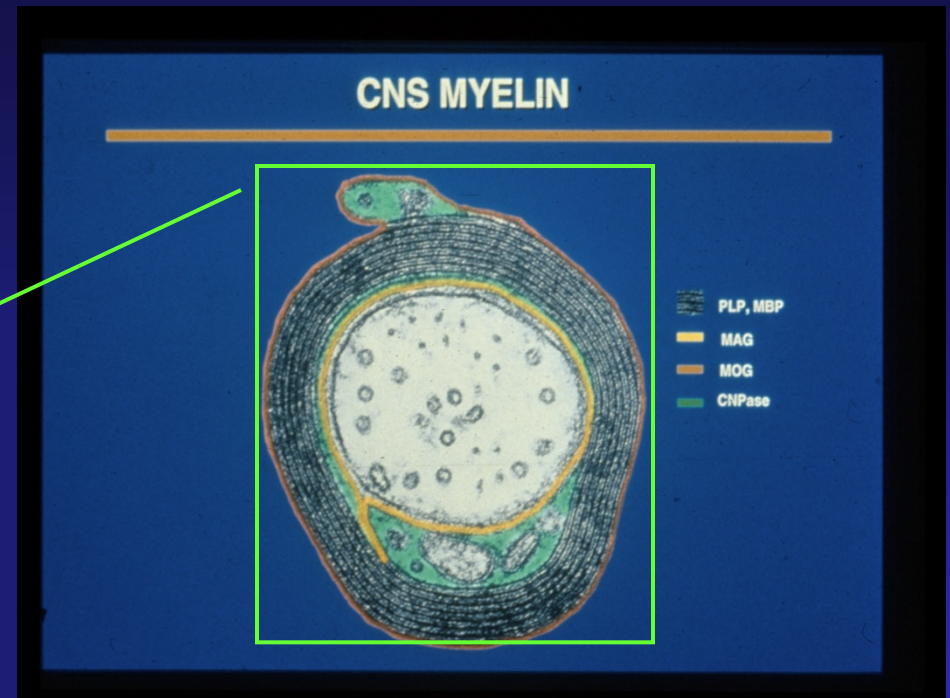
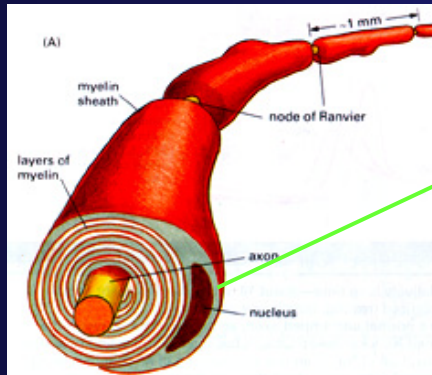
4. Subtle abnormalities of blood T cell functions

- Slightly increased frequency and reduced requirements for activation of T cells responding to myelin antigens
- Prevalence of T helper 1 cytokine secretion by *myelin* antigen-specific T cells
- Likely role of Th17 cells in driving inflammation
- Reduced activity of (CD4+/CD25+) regulatory T cells

CNS antigens – but which?



Candidate target myelin antigens in MS



Myelin basic protein (MBP); 170 aa, several isoforms)

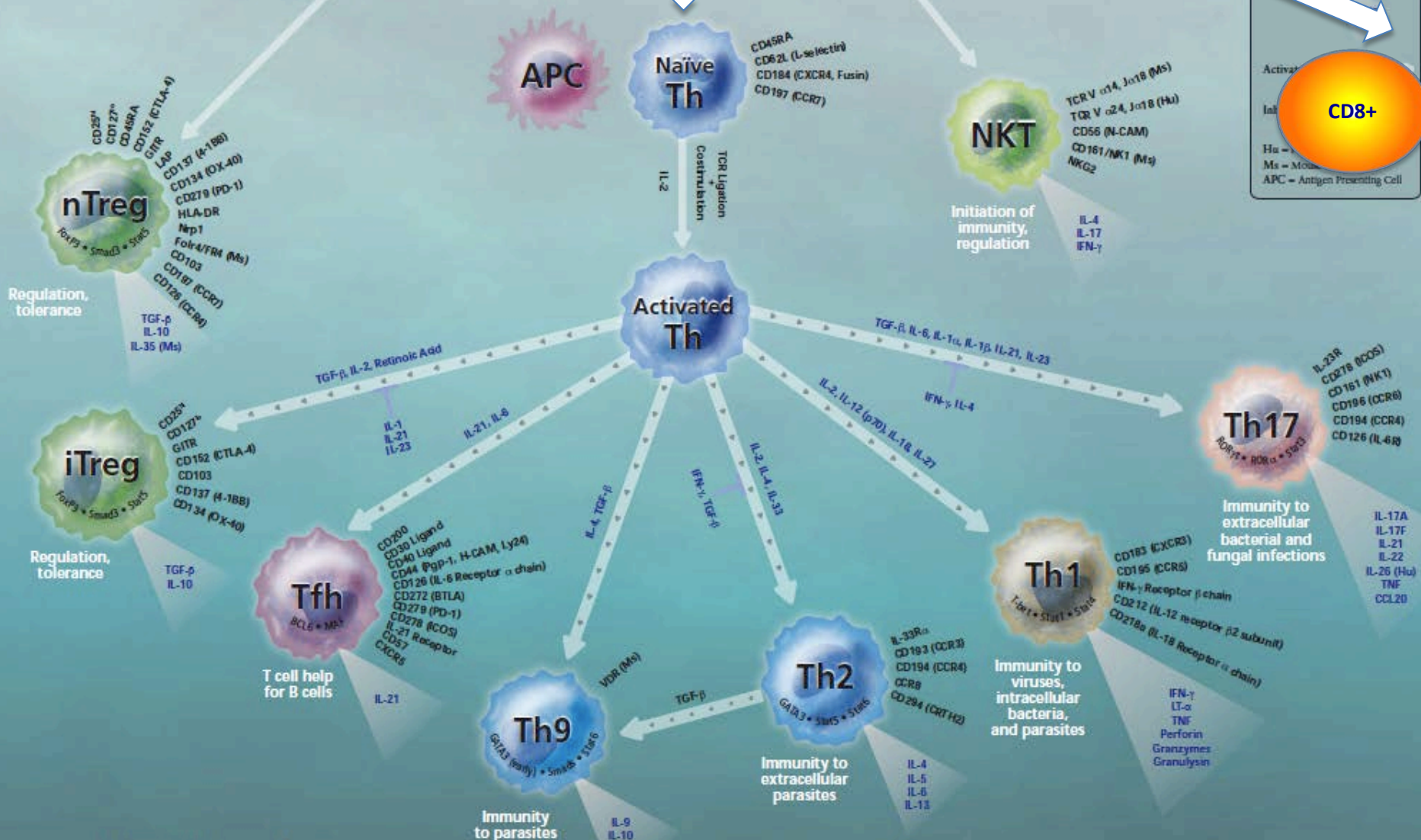
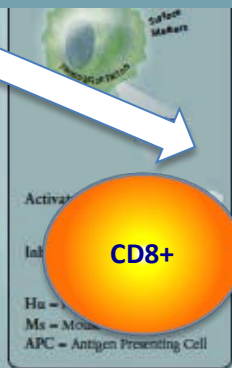
Proteolipid protein (PLP); 272 aa, two isoforms)

Myelin oligodendroglia glycoprotein (MOG); target of T- and B cell response)

A few others

THYMUS
PERIPHERY

CD4+8+



Is CNS immunopathology initiated by Th17 cells?

- IL-17A expressed at relatively high levels in circulating leukocytes and cerebrospinal fluid mononuclear cells of patients with MS, particularly during relapses
- IL-17A transcripts were elevated in MS plaques compared to brain tissues from control subjects by microarray
- presence of IL-17A+ cells in active areas of MS lesions by immunocytochemistry
- CD8+, as well as CD4+, T cells equally immunostained for IL-17 in MS tissues
- In a patient with aggressive relapsing remitting MS, transcripts encoding retinoic acid-related orphan nuclear hormone receptor C (RORC; the hallmark transcription factor of Th17 differentiation) were upregulated in an acute lesion compared to normal appearing white matter

Pathogenic CD8 T cells?

- CD8 are the most frequent T-cell subset seen in acute and chronic lesions, outnumbering CD4⁺ T cells 3- to 10-fold in chronically inflamed MS plaques
- there is specific enrichment of highly differentiated CD8⁺ rather than CD4⁺ T cells in the CSF in relapsing-remitting and possible MS patients
- CD8 T cells show oligoclonal expansions in MS brains, blood, and CSF that have not been reported for CD4⁺ T cells

MS as a disease of regulatory T cell dysfunction?

Loss of Functional Suppression by CD4⁺CD25⁺ Regulatory T Cells in Patients with Multiple Sclerosis

Vissia Viglietta, Clare Baecher-Allan, Howard L. Weiner, and David A. Hafler

*Laboratory of Molecular Immunology, Center for Neurologic Diseases, Brigham and Women's Hospital,
Harvard Medical School, Boston, MA 02115*

- In patients with multiple sclerosis, the function of peripheral CD4⁺ T_{Reg} cells seems to be impaired... J Exp Med 199, 971



Research article

Patients with relapsing-remitting multiple sclerosis have normal Treg function when cells expressing IL-7 receptor α -chain are excluded from the analysis

Laure Michel,^{1,2} Laureline Berthelot,¹ Ségolène Pettré,¹ Sandrine Wiertelowski,^{2,3} Fabienne Lefrère,³ Cécile Braudeau,¹ Sophie Brouard,¹ Jean-Paul Soullillou,¹ and David-Axel Laplaud^{1,2,3}

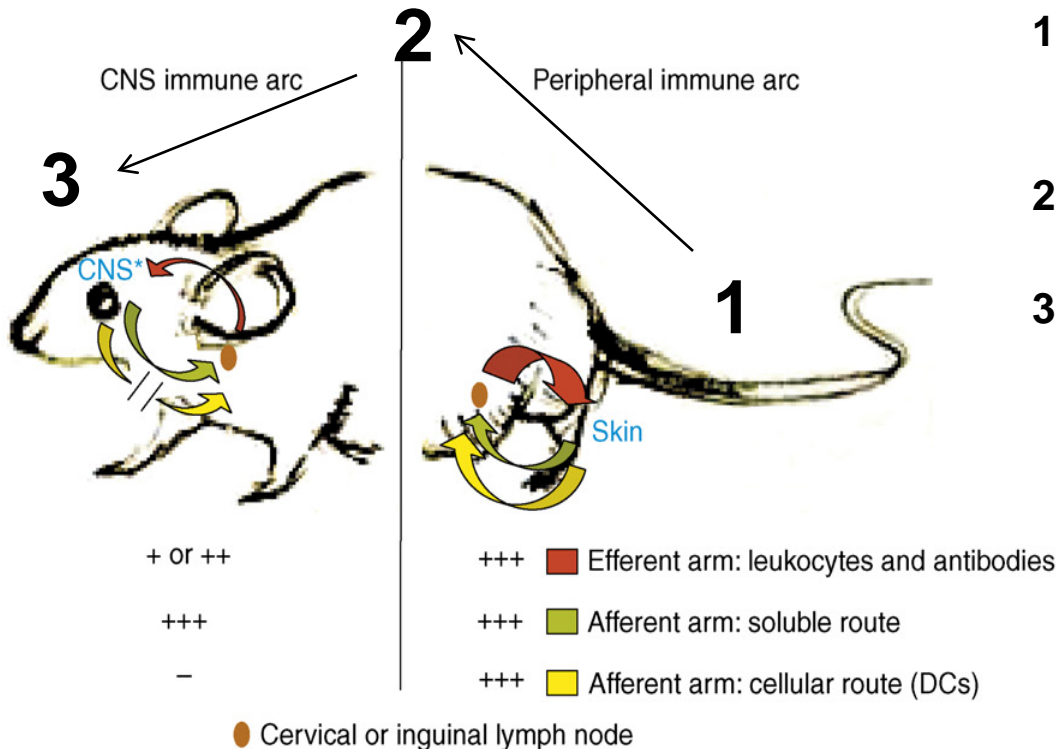
“...we conclude that CD4⁺CD25^{high}CD127^{low} Tregs from MS patients and healthy individuals exhibit similar suppressive functions.

J Clin Invest 118, 3411

5. Animal models of autoimmune disease

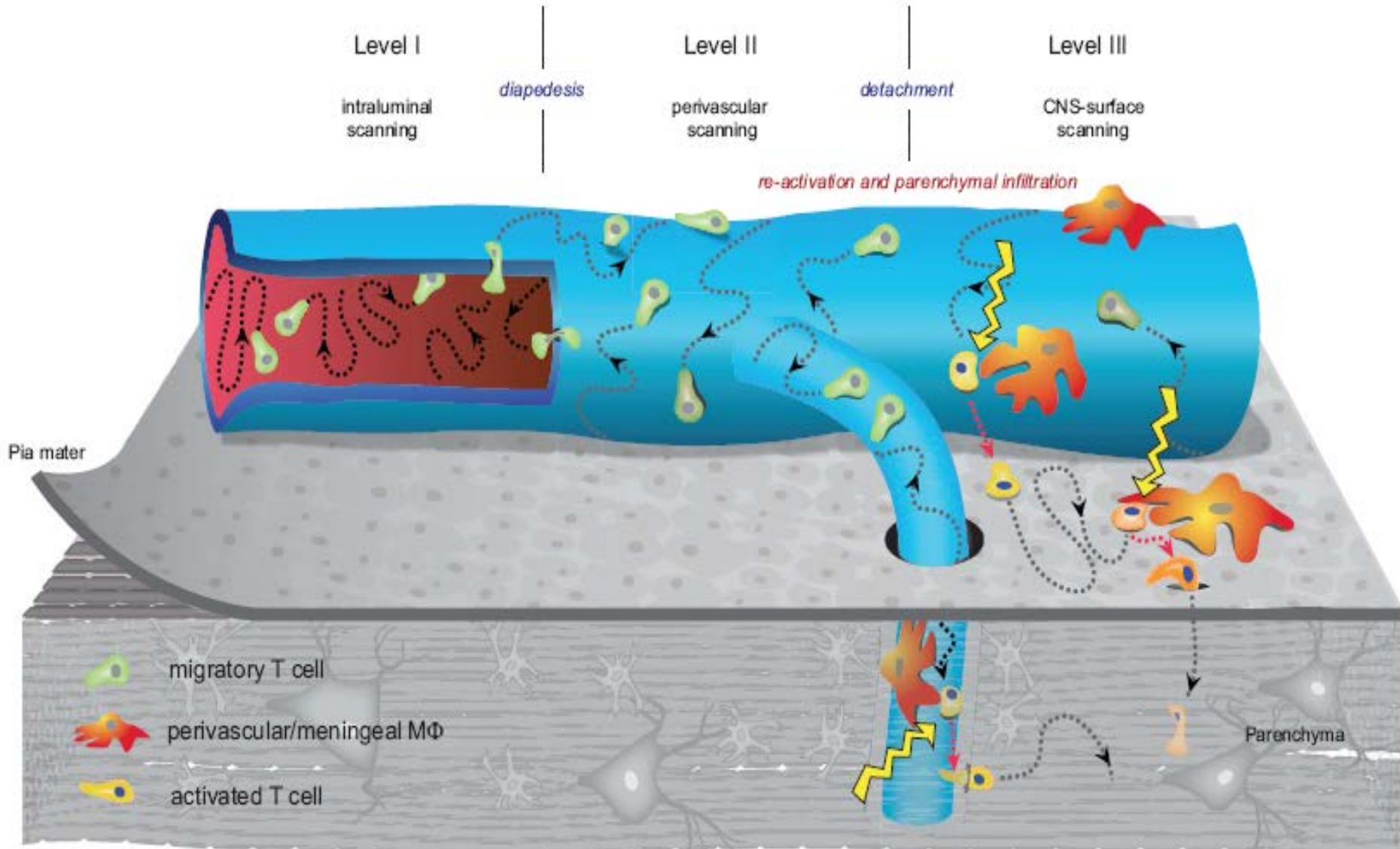
Experimental allergic encephalomyelitis (EAE):

- Induced by peripheral immunisation with myelin protein antigens
- Mediated by CD4+ myelin-specific T cells



- 1) Autoreactive myelin-specific effector T cells are primed in peripheral lymph nodes and
- 2) Migrate into uninflamed CNS to initiate tissue inflammation.
- 3) Antigen re-encounter in CNS propagates inflammation and damage

Invasion steps of encephalitogenic T cells into their target organ



6. Comorbidity and similarities with other autoimmune diseases

Patients with MS have increased incidence of some autoimmune conditions (best evidence is for thyroiditis) and asymptomatic positivity for autoantibodies

MS share with Rheumatoid Arthritis, Systemic lupus Erythematosus, autoimmune thyroiditis and other autoimmune disorders features such as:

- higher incidence in females,
- young adult onset,
- initially relapsing course

7. Response to immuno-suppressive and -modulatory therapies

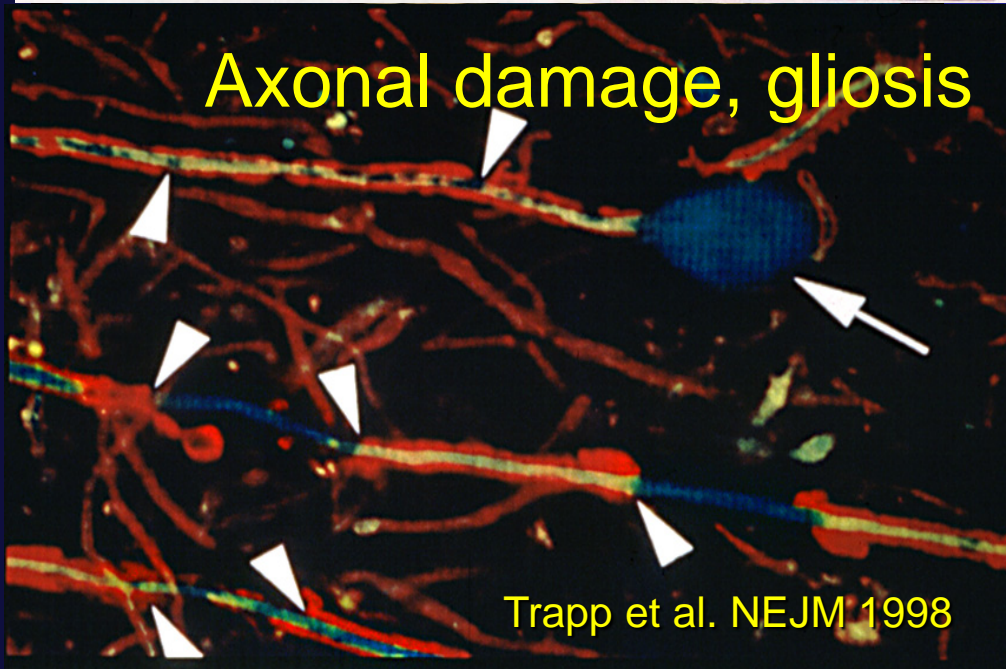
MS acute relapses are improved by high-dose corticosteroid administration

The clinical course of MS is attenuated by immuno-modulatory treatment (e.g. interferon beta), by treatments blocking immune cell entry to the CNS (anti-alpha-4 integrin blockade: natalizumab) and by immuno-suppressive and cytotoxic agents (e.g. Mitoxantrone)

Inflammation and demyelination



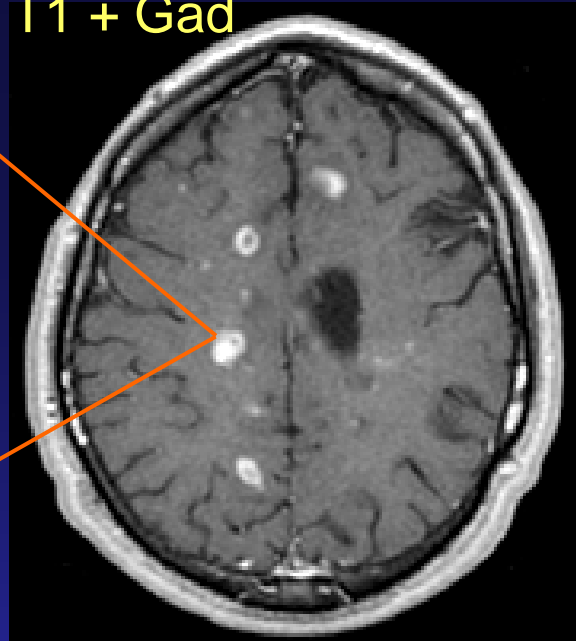
Axonal damage, gliosis



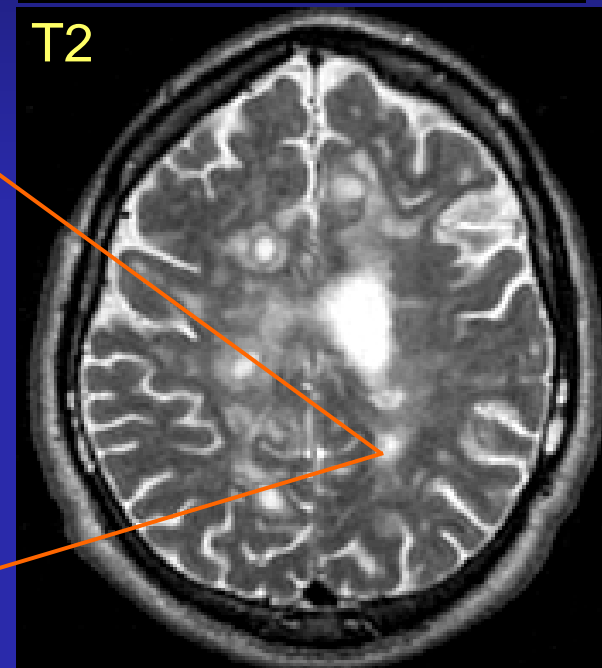
Trapp et al. NEJM 1998

MRI

T1 + Gad



T2



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Mechanisms of neuronal loss in MS

INDIRECT

- neuronal changes due to inflammation/demyelination induced axonal mitochondrial insufficiency

DIRECT (mostly immune-mediated)

- direct effect of inflammatory mediators produced by immune cells on neuronal perikarya in grey matter lesions
- direct effect of low level release of inflammatory mediators by **activated microglia** in normal appearing tissues

Unresolved

Take home points

- MS is an inflammatory, likely autoimmune demyelinating and axonal disorder of the CNS
- Initiated by CD4 and/or CD8 T cells infiltrating the CNS, propagated by T cells, B cells, and plasma cells, with macrophages as common effector arm and a possible role of microglia
- Axonal degeneration is at least initially strictly dependent on inflammation, but may progress independently later on

Recommended reading

Books:

- McAlpine's Multiple Sclerosis, Fourth Edition, Churchill Livingstone, 2005 (relevant sections)

Review and original articles:

- Compston & Coles (2008) Multiple Sclerosis. Lancet.
- Prineas et al (2001) Immunopathology of secondary progressive MS. Ann Neurol 50:646-657.
- Peterson et al (2001) Transected neurites, apoptotic neurons, and reduced inflammation in cortical MS lesions. Ann Neurol 50:389-400.
- Kutzelnigg et al (2005) Cortical demyelination and diffuse white matter injury in MS. Brain 128:2705-2712.
- Magliozzi et al (2007) Meningeal B-cell follicles in secondary progressive MS associate with early onset of disease and severe cortical pathology. Brain 130:1089-1104.

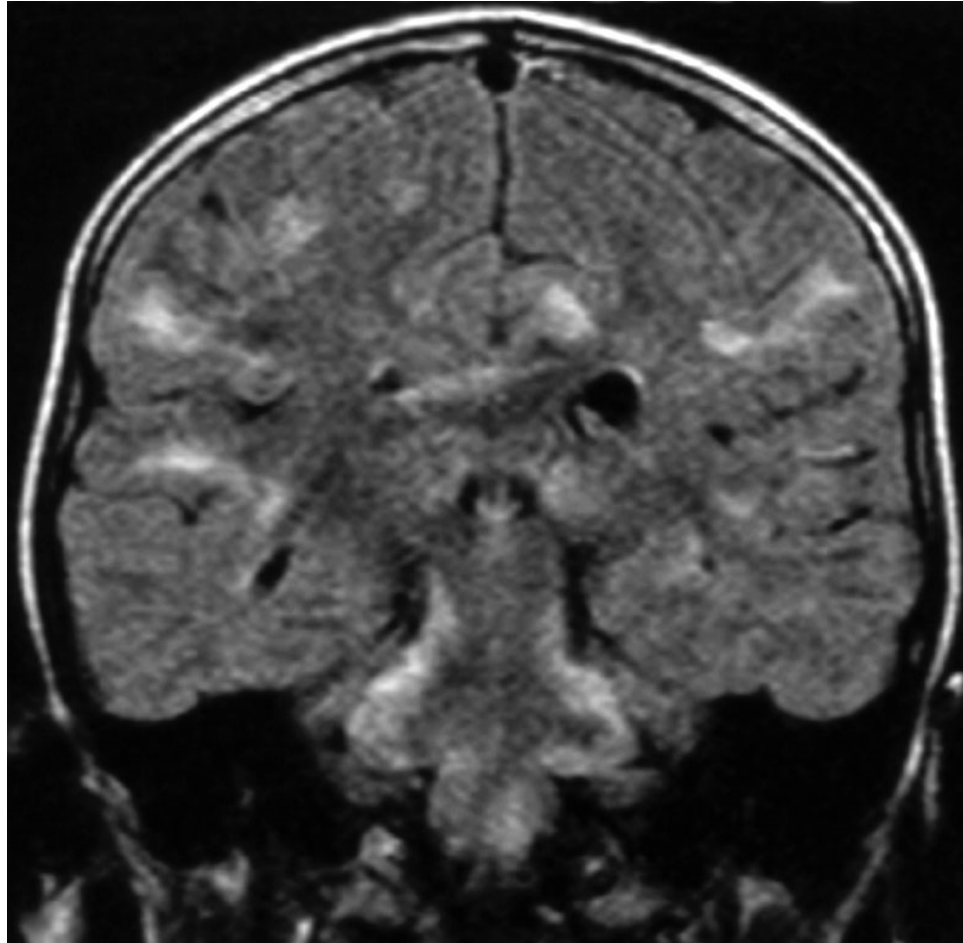
Some of the many other CNS inflammatory disorders

- **CNS-specific inflammatory syndromes**
 - Acute disseminated encephalomyelitis
 - Neuromyelitis optica
- **Systemic immune diseases affecting the CNS**
 - Neurosarcoidosis
 - Systemic lupus erythematosus
 - Anti-phospholipid syndrome
 - Sjogren's syndrome

Acute disseminated encephalomyelitis (ADEM)

- Childhood age of onset
- Usually antecedent infection or immunization
- Molecular targets unknown
- Monophasic
- Fever, headache, meningism
- Seizures, coma
- Multifocal neurological deficits
- Bilateral optic neuritis
- Usually good recovery with marked resolution of lesions at follow up

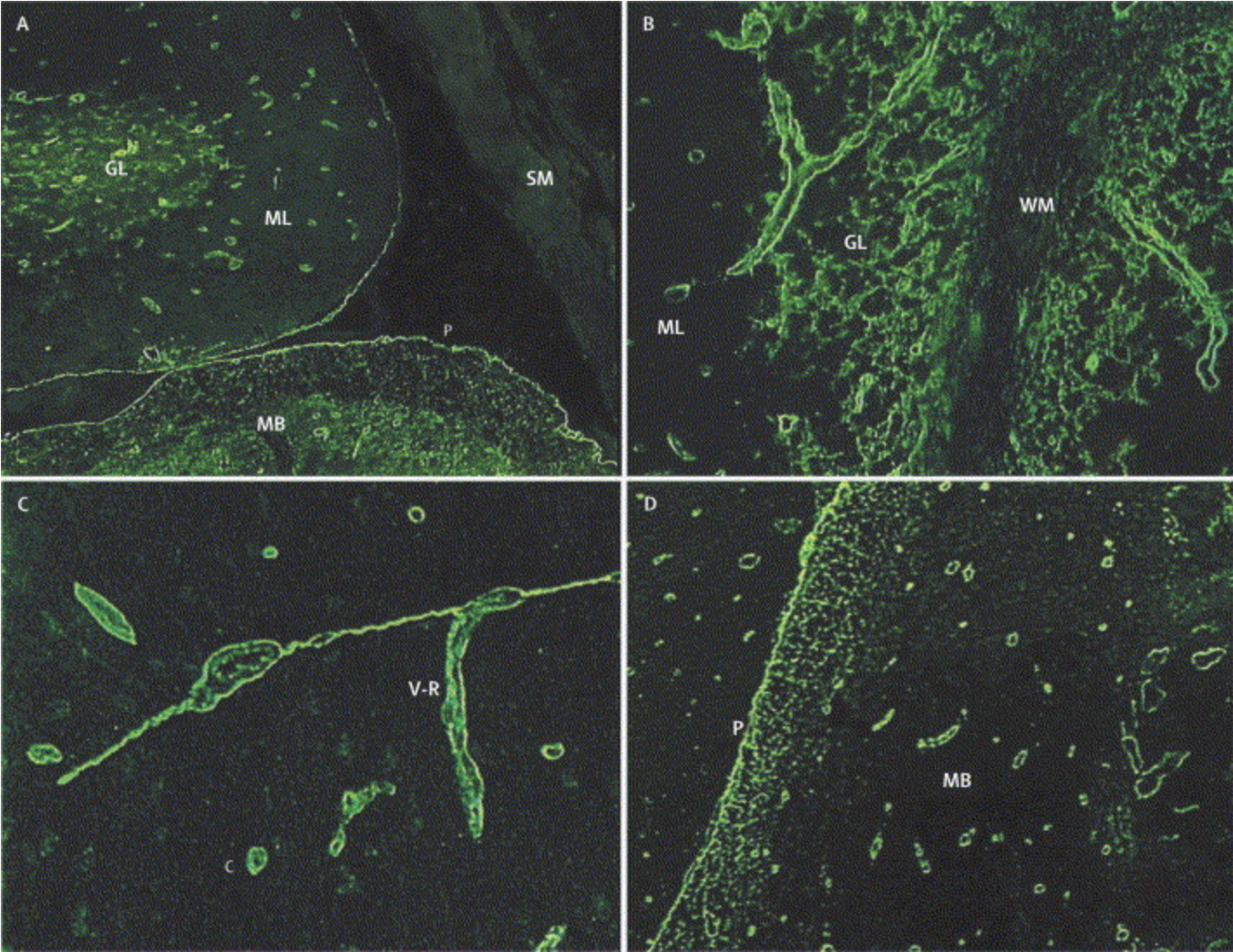
Coronal FLAIR sequence of a boy aged 8 showing multiple areas of high signal within the white matter, typical of ADEM



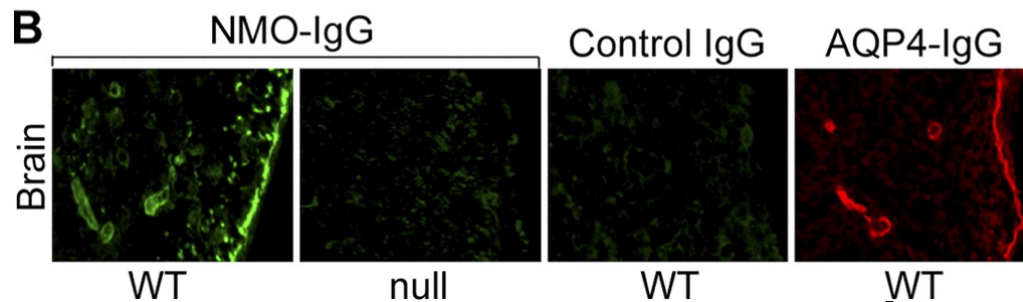
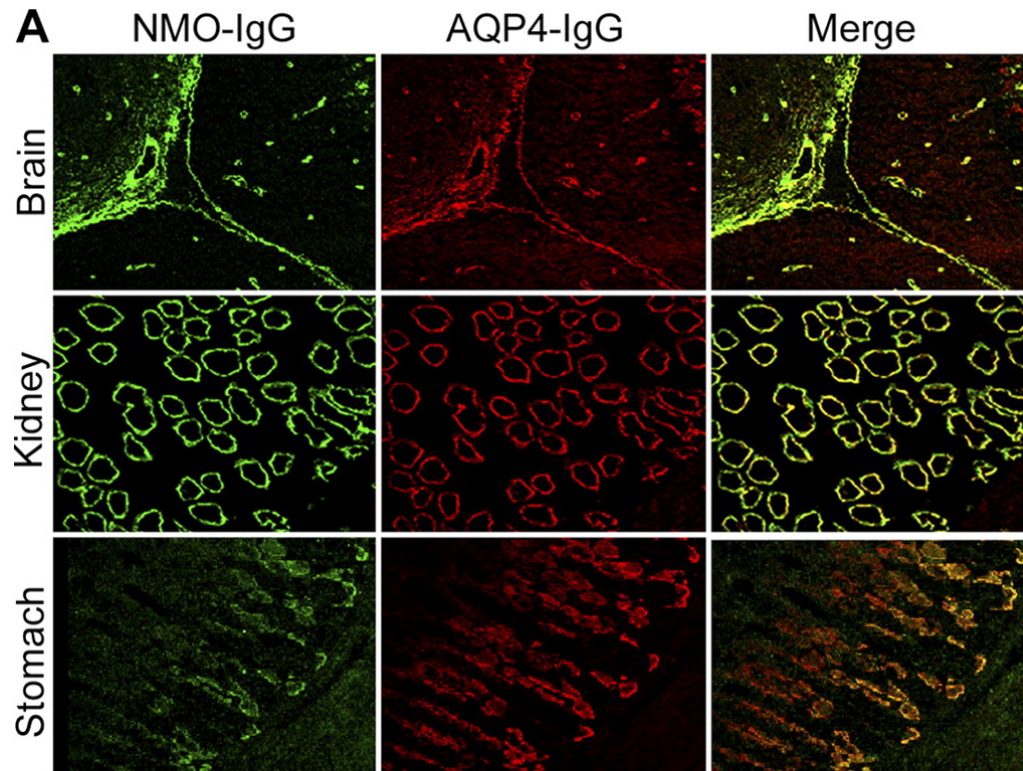
Neuromyelitis optica (NMO) – a newly recognized CNS channelopathy

- NMO (Devic's disease) is a clinically defined severe CNS demyelinating syndrome characterized by optic neuritis and acute myelitis
- Characteristic immunopathology: IgG, IgM and complement deposited in a vasculogenic pattern suggest role for autoantibody
- IgG specific for NMO in serum of 73% of patients; binds to the **aquaporin-4** water channel

Immunofluorescence pattern of bound NMO-IgG in mouse CNS



Immunofluorescence reveals NMO-IgG colocalization with AQP4 in mouse tissues



Take-home points

- MS: inflammatory + demyelinating + degenerative disease of the CNS
- Role of T, B cells and macrophages in pathogenesis
- Molecular targets not clearly identified
- Differential diagnosis includes
 - ADEM
 - NMOWhich have different evolution and underlying pathologies