# An Update on Immunopathogenesis, Diagnosis and Treatment of Multiple Sclerosis

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## Abstract

### Background

Multiple sclerosis is an acquired demyelinating disease of the central nervous system. It is the second most common cause of disability in adults in United States after head trauma.

### Discussion

The etiology of MS is probably multifactorial, related to genetic, environmental, and several other factors. The pathogenesis is not fully understood but is believed to involve T-cell mediated inflammation directed against myelin and other related proteins with a possible role for B-cells. The McDonald criteria have been proposed and revised over the years to guide the diagnosis of MS and are based on clinical presentation and magnetic resonance imaging (MRI) of the brain and spinal cord to establish dissemination in time and space. The treatment of MS includes disease modification with immunomodulator drugs and symptom management to address the specific symptoms such as fatigue, spasticity, and pain.

### Conclusion

An update on etiology, pathogenesis, diagnosis, and immunomodulatory treatment of MS is presented.

## Keywords

* Multiple Sclerosis
* etiology
* pathogenesis
* diagnosis
* demyelination
* treatment
* immunomodulator

## Introduction

Multiple sclerosis is an autoimmune inflammatory disorder of CNS of unknown etiology, characterized by demyelination and variable degrees of axonal loss. The disease affects mostly young women (between ages 20-40 years) and is one of leading causes of disability in young adults in US (Orton, et al. 2006, Kister, et al. 2013). Its prevalence in the US is about 400,000 and over two million people are affected worldwide with an expected increase in the number of cases in future (B. G. Weinshenker 1996, Mayr, et al. 2003).The disease appears to be more common in northern hemisphere and there is some genetic susceptibility as well in individuals of Scandinavian or northern European ancestry (Williams, et al. 1995, Compston and Coles 2008). The etiology although unknown presumably involves interaction between genetic, environmental and other factors triggering an aberrant autoimmune attack resulting in damage to myelin and axons (Brück and Stadelmann, The spectrum of multiple sclerosis: new lessons from pathology 2005). The course of MS can be variable with a significant proportion of patients experiencing some progression following the initial relapsing remitting phase leading to significant disability (Weinshenker, et al. 1989, Lublin and Reingold, Defining the clinical course of multiple sclerosis results of an international survey 1996). Much progress has been made in the past two decades in treating MS with the advent of effective immunomodulatory therapies which can potentially slow down the progression and alter the disease course.

## Etiology

The etiology of MS remains unknown; however, it is believed to be caused by immune dysregulation triggered by genetic and environmental factors (Ascherio and Munger, Environmental risk factors for multiple sclerosis. Part I: The role of infection 2007, Ascherio and Munger, Environmental risk factors for multiple sclerosis. Part II: Noninfectious factors 2007). Although MS is not an inherited disease, there is a strong genetic component to its etiology as evidenced by clustering of MS cases within families. The risk of MS among first-degree relatives of MS patients is 10- to 50 times higher than the general population (absolute risk 2-5%); the concordance rate in monzygotic twins is about one third (B. G. Weinshenker 1996, Kantarci 2008). Linkage analysis studies have revealed several gene loci as risk factors, with the major histocompatibility complex (MHC) HLA DR15/DQ6 allele being the strongest one (Barcellos, et al. 2003, International Multiple Sclerosis Genetics Consortium; Wellcome Trust Case Control Consortium 2 2011). More recently, alleles of interleukin-2 receptor alpha gene (IL2RA) and interleukin-7 receptor alpha gene (IL7RA)have also been identified as inheritable risk factors (International Multiple Sclerosis Genetics Consortium 2007, International Multiple Sclerosis Genetics Consortium; Wellcome Trust Case Control Consortium 2 2011). However, most of the genetic factors underlying susceptibility still remain to be defined. Furthermore genetic susceptibility does not fully explain the changes in MS risk that occur with migration suggesting a likely role for environmental factors.

Among environmental factors, Epstein-Barr virus (EBV) infection and vitamin D deficiency have been extensively studied and strongly linked to MS risk (Ascherio and Munger, Environmental risk factors for multiple sclerosis. Part I: The role of infection 2007, Ascherio and Munger, Environmental risk factors for multiple sclerosis. Part II: Noninfectious factors 2007). MS is prevalent in geographical areas farther away from the equator (Simpson, et al. 2011). Low vitamin D levels from reduced sun exposure may be a factor contributing to increased susceptibility to MS in these regions (Correale, Ysrraelit and Gaitán 2009, Ascherio and Munger, Environmental risk factors for multiple sclerosis. Part II: Noninfectious factors 2007, Ascherio, Munger and Simon, Vitamin D and multiple sclerosis 2010). Studies have suggested that higher levels of vitamin D have a possible protective role in certain susceptible patient populations (Munger, Levin, et al. 2006, Munger, Zhang, et al. 2004). The risk of developing MS is approximately 15-fold higher among individuals with a history of EBV infection in childhood and about 30-fold higher among those infected with EBV in adolescence or later in life (Ascherio, Environmental factors in multiple sclerosis 2013). However, the difference in the risk of MS among migrants from high to low MS prevalence areas suggests that other infectious or noninfectious factors in addition to EBV may be involved (Ascherio and Munger, Environmental risk factors for multiple sclerosis. Part I: The role of infection 2007, Ascherio and Munger, Environmental risk factors for multiple sclerosis. Part II: Noninfectious factors 2007). The "hygiene hypothesis," supported by many epidemiological observations, suggests that improved sanitation and reduced childhood infections in developed countries may account for the increased rates of autoimmune diseases (T-helper 1mediated) and allergy (T-helper 2 mediated) (Conradi, et al. 2011). However, this hypothesis does not explain the higher MS prevalence in rural compared to urban areas (with expected improved sanitation) reported in some studies (Stefano, et al. 2003).

Cigarette smoking has also been proposed at a potential environmental risk factor with several studies reporting an association between smoking and MS risk and disease activity (Wingerchuk 2012). The odds ratio for developing MS is approximately 1.5 for smokers compared with nonsmokers (Wingerchuk 2012, Fragoso 2014). As with other risk factors, smoking appears to influence the MS susceptibility in conjunction with the genetic and other environmental factors.

There is no specific diet associated with increased risk of MS. The role of dietary factors appears to be complex and related to the influence of multiple dietary components including vitamin A and D, salt, omega-3-unsaturated fatty acid, and polyphenol on immune regulation. Some recent reports have suggested that salt modulates the differentiation of human and mouse Th17 cells (Wu, et al. 2013, Kleinewietfeld, et al. 2013). A more aggressive course of experimental autoimmune encephalomyelitis (EAE) was observed in mice fed a high sodium diet. In a small observational study, higher sodium intake was associated with increased clinical and radiological disease activity in patients with MS (Farez, et al. 2015).

The potential risk factors for MS are listed in Table 1.

Table 1.

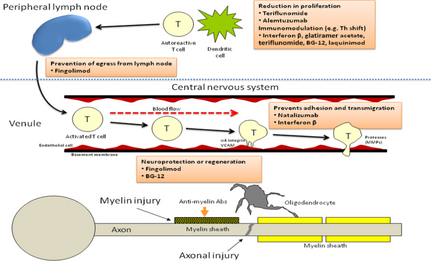
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| --- |
| Potential risk factors for multiple sclerosis |
| Female gender |
| Caucasian race |
| Genetic |
| HLA DR15/DQ6, IL2RA and IL7RA alleles |
| Infections |
| Epstein-Barr virus (EBV) infection |
| Temperate climate |
| Low vitamin D level |
| Lack of sunlight exposure |
| Cigarette smoking |

## Immunopathogens

The pathogenesis of MS involves immune attack against CNS antigens mediated through activated CD4+ myelin-reactive T cells with a possible contribution by B cells. Much of our understanding of immunopathogenesis of MS is derived from the study of experimental autoimmune encephalomyelitis (EAE), an animal model of CNS inflammatory demyelination that can be induced by peripheral immunization with myelin protein components. EAE shares many of the histological features of MS including active demyelination, oligodendrocyte and axonal loss, all of which are presumably mediated by myelin specific T cells (Yong 2004, Gold, Linington and Lassmann, Understanding pathogenesis and therapy of multiple sclerosis via animal models: 70 years of merits and culprits in experimental autoimmune encephalomyelitis research 2006). The immunopathogenesis of MS is thought to involve a breach of self-tolerance towards myelin and other CNS antigens resulting in persistent peripheral activation of autoreactive T cells (Hafler, et al. 2005, Selter and Hemmer 2013). In a genetically susceptible individual, this loss of self-tolerance may be triggered by an environmental antigen, presumably an infectious agent such as a virus. The infection could cause bystander activation of T cells or result in release of autoantigens due to cellular damage, which can then lead to activation of T cells by cross reactivity between an endogenous protein (e.g. myelin basic protein) and the pathogenic exogenous protein (viral or bacterial antigen), a process known as molecular mimicry (Fujinami and Oldstone 1985, Wucherpfennig and Strominger 1995, Aichele, et al. 1996, Gran, et al. 1999, O'Connor, Bar-Or and Hafler 2001).

As depicted in Figure 1, once activated in the periphery, myelin-reactive T cells are able to migrate across the blood brain barrier (BBB). The transmigration process involves interaction between very late antigen-4 (VLA-4) present on T lymphocytes and the vascular cell adhesion molecule-1 (VCAM-1) expressed on capillary endothelial cells; this process is facilitated by expression and upregulation of various adhesion molecules, chemokines, and matrix metalloproteinases (MMPs) (Yong 2004, Gold and Wolinsky 2011). After entering the CNS, the autoreactive peripherally activated T cells can be reactivated upon encountering the auto-antigenic peptides within the brain parenchyma in the context of MHC class II molecules expressed by local antigen presenting cells (dendritic cells, macrophages, and B cells) triggering an inflammatory cascade leading to release of cytokines and chemokines, recruitment of additional inflammatory cells including T cells, monocytes, and B cells and persistent activation of microglia and macrophages resulting in myelin damage (Hemmer, Archelos and Hartung 2002, Frohman, Racke and Raine 2006, Inglese 2006). The local inflammation and demyelination results in exposure of sequestered myelin autoantigens providing an additional target for self-reactive T cells, a phenomenon called “epitope spreading” (Miller, et al. 1997). Activation of resident CNS glial cells (such as microglia) results in persistent inflammation even in absence of further infiltration of exogenous inflammatory cells (O'Connor, Bar-Or and Hafler 2001). The evidence based on animal studies suggests that CD4+ T-helper 1 (TH1) cells which release proinflammatory cytokines such as interferon-gamma, interleukin-2 (IL-2), and tumor necrosis factor-*α* (TNF-*α*) are the key players in mediating inflammation in MS with some role for the novel CD4+ T-helper-17 (TH17) cell subset which secretes IL-17 (O'Connor, Bar-Or and Hafler 2001, Selter and Hemmer 2013). The CD4+ T-helper 2 (TH2) cells, which secret interleukins 4, 5, and 10 are believed to have a counter regulatory role limiting theTH1 cell mediated injury (Tzartos, et al. 2008). The TH1/ TH2 paradigm is more apparent in EAE; in MS, indirect evidence exists for a predominant role of Th1 cells based on the success of therapies that shift the cytokine profile away from Th1 towards Th2. CD8+ T cells are believed to be involved as well and can induce axonal pathology by direct injury to MHC I/antigen expressing cells such as neurons and oligodendrocytes (Batoulis, Addicks and Kuerten 2010). The contribution of B cells to MS pathogenesis (possibly through autoantibody secretion and antigen presentation to T cells) has recently been recognized and is supported by observed pathologic heterogeneity of MS lesions, the presence of meningeal inflammation and B cell follicle-like structures adjacent to subpial cortical lesions, and the success of B cell based immunotherapies (O'Connor, Bar-Or and Hafler 2001, Batoulis, Addicks and Kuerten 2010, Naismith, et al. 2010).

Figure 1. Immunopathogenic mechanisms in MS and proposed targets of different disease modifying therapies



Although demyelination is the hallmark of MS pathology, early axonal injury and axonal loss also occur and may drive disability progression (Trapp, et al. 1998). The exact mechanism(s) of both myelin and axonal injury are not completely understood, but are likely to include both direct injury to myelin and oligodendrocytes, and axons by CD4+ and CD8+ T lymphocytes, activated microglia/macrophages and/or antibody and complement as well as the indirect effects of proinflammatory cytokines such as IL-1beta, TNF-*α*, nitric oxide, and MMPs (Lucchinetti, et al. 2000, Hemmer, Archelos and Hartung 2002, Gold and Wolinsky 2011). Meningeal inflammatory infiltrates reported in association with subpial cortical lesions may contribute to cortical inflammation and disability in some cases (Howell, et al. 2011, Lucchinetti, et al. 2011).

## Pathology

The MS plaques or lesions are focal areas of demyelination associated with variable inflammation and axonal loss that predominantly affect the white matter of the brain, spinal cord, and optic nerves but can also involve the cerebral cortex including subpial regions (Popescu and Lucchinetti 2012, Sobel and Moore 2008). The inflammatory infiltrates associated with plaques consist of activated T cells (predominantly CD8+ with variable presence of CD4+ cells), activated macrophages/microglia, plasma cells, and B cells (Hauser, et al. 1986, O'Connor, Bar-Or and Hafler 2001). MS plaques can be further classified histologically as active, chronic, and remyelinated. Active lesions are common in relapsing remitting MS and are characterized by myelin degradation (with relative axonal preservation), macrophage infiltration, reactive astrocytes, and perivascular and parenchymal inflammation (Brück, Porada, et al. 1995, Frischer, et al. 2009). Chronic or inactive plaques are more often seen in patients with progressive disease and are associated with more extensive demyelination, often with marked axonal depletion, loss of oligodendrocytes and relative absence of active inflammation (Prineas, et al. 2001, Sobel and Moore 2008, Popescu and Lucchinetti 2012). Remyelinated plaques are seen within or more often at the margins of active plaques and contain thinly myelinated axons and often increased numbers of oligodendrocyte precursor cells (Brück, Porada, et al. 1995, Popescu and Lucchinetti 2012). “Shadow plaques” are lesions that show more diffuse (but still incomplete) remyelination and are seen in patients with relapsing and progressive disease (Barkhof, et al. 2003). The presence of cortical demyelination and axonal loss has been increasingly recognized in early MS (Trapp, et al. 1998, Cifelli, et al. 2002). Lucchinetti and colleagues (2000) have described four distinct immmopathological patterns (pattern I with macrophage and T cell predominance, II with additional immunoglobulin and complement deposition, III with apoptotic oligodendrocyte loss, and the rare type IV pattern with nonapoptotic death of oligodendrocytes) in active MS lesions, suggesting that there may be pathological heterogeneity among MS patients. However, the observed pathologic heterogeneity may not be exclusive to a subset of MS patients and is probably related to the stage of disease in a given patient (Lucchinetti, et al. 2011). Cortical involvement can occur in MS and may reflect either the presence of cortical demyelination or actual neuronal loss. Within the cortex, three distinct lesion types have been described based on the location of the plaques: subpial, intracortical, and leukocortical (Popescu, Pirko and Lucchinetti 2013). Cortical lesions seen in early MS are usually highly inflammatory and correlate with cognitive impairment (Geurts and Barkhof 2008, Lucchinetti, et al. 2011).

## Clinical Presentation and Diagnosis

The clinical symptoms and signs of MS are variable and may result from involvement of sensory, motor, visual, and brainstem pathways. The majority of patients with MS initially present with relapsing remitting episodes of new or recurrent neurological symptoms. The first clinical event in these patients, termed clinically isolated syndrome (CIS), can be optic neuritis, incomplete myelitis, or brainstem syndrome (Miller, et al. 2005). The presence of classic demyelination lesions on baseline brain or spinal cord MRI is the most important predictor of having a second relapse in CIS patients (Filippi, et al. 1994). The presence of cerebrospinal fluid (CSF) abnormalities (positive oligoclonal bands) may have additional prognostic value in patients with CIS and positive brain MRI (Miller, et al. 2005, Awad, et al. 2010). A variable proportion of patients with relapsing remitting MS (25-40%) develop secondary progressive disease over time with progressive accumulation of disability with infrequent or no relapses (Lublin and Reingold, Defining the clinical course of multiple sclerosis results of an international survey 1996). Primary progressive MS (seen in approximately 10-15% patients) is defined by progressive accumulation of disability from the onset with no or minor relapses and typically presents with a progressive myelopathy with an older age of onset and involving a higher proportion of men (Miller and Leary, Primary-progressive multiple sclerosis 2007). Both primary and secondary progressive MS share some clinical and imaging features and are now considered to be part of the progressive disease spectrum (Lublin and Reingold, Defining the clinical course of multiple sclerosis results of an international survey 1996, Ingle, et al. 2005, Lublin, Reingold and Cohen, et al. 2014). The progressive relapsing form of MS with worsening disability from onset and clear acute relapses with or without full recovery is now considered to be progressive disease with disease activity (Lublin, Reingold and Cohen, et al. 2014).

There is no single diagnostic test for MS and the diagnosis is usually based on the clinical presentation, supported by neuroimaging and in some cases by CSF analysis (to look for inflammatory markers oligoclonal bands and/or elevated IgG index) and evoked potential studies (to look for clinically silent lesion in visual, brainstem, or spinal cord pathways). CSF inflammatory markers are present in upto 85% patients with MS (Link and Huang 2006); IgG index is less sensitive and specific than oligoclonal bands (Awad, et al. 2010). There have been several proposed diagnostic criteria incorporating the clinical and ancillary data, the most commonly used one is the McDonald criteria initially proposed in 2001 and revised in 2005 and most recently in 2011 (Polman, Reingold, et al. 2011). The basic concept behind these criteria is demonstration of dissemination in time (DIT) and space using the clinical and/or MRI data. A detailed discussion of McDonald criteria is beyond the scope of this review; in summary, the definitive diagnosis of MS requires ≥ 2 attacks or objective clinical evidence of ≥ 2 lesions or objective clinical evidence of 1 lesion with historical evidence of a prior attack. With one clinical attack, DIT can be demonstrated by presence of asymptomatic gadolinium-enhancing and non-enhancing lesions at any time or by presence of new lesions on a follow-up scan obtained anytime after the initial symptom onset or the simultaneous (see Table 2). Dissemination in space (DIS) in a patient with two clinical attacks but objective evidence of one lesion can be demonstrated by using the MRI criteria detailed in Table 3. The criteria for primary progressive MS include one year of disease progression plus two of the following criteria: a. evidence of DIS in brain, b. DIS in spinal cord (≥ 2 T2 lesions in the cord), c. positive CSF oligoclonal bands and/or elevated IgG index.

Table 2. McDonald MRI Criteria for Demonstration of DIT (Polman, Reingold, et al. 2011). MRI= magnetic resonance imaging; DIT= lesion dissemination in time. Based on: Montalban et al. (2010). Adapted from: Polman, Reingold et al. (2011).

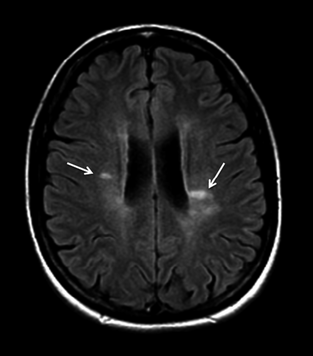
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| DIT Can be Demonstrated by: |
| 1. A new T2 and/or gadolinium-enhancing lesion(s) on follow-up MRI, with reference to a baseline scan, irrespective of the timing of the baseline MRI |
| 2. Simultaneous presence of asymptomatic gadolinium-enhancing and nonenhancing lesions at any time |

Table 3. McDonald MRI Criteria for Demonstration of DIS (Polman, Reingold, et al. 2011). MRI= magnetic resonance imaging; DIS= lesion dissemination in space; CNS= central nervous system. Adapted from: Polman, Reingold et al. (2011); Based on: Swanton et al. (2006); Swanton et al. (2007).

|  |
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| DIS Can be Demonstrated by ≥1 T2 lesions[[3]](#footnote-3) in at Least 2 of the 4 Area of the CNS |
| Periventricular |
| Juxtacortical |
| Infratentorial |
| Spinal cord[[4]](#footnote-4) |

In patients presenting with typical relapsing remitting symptoms and classic demyelination lesions (example shown in Figure 2) on neuroimaging meeting the radiological criteria, the differential diagnosis is limited and often no further diagnostic testing is indicated in these cases.

Figure 2. Brain MRI axial fluid attenuated inversion recovery (FLAIR) image shows the characteristic periventricular areas of increased signal intensity (arrows) that are oriented perpendicular to and often contiguous with the lateral ventricles.



The differential diagnosis in other cases depends on the clinical presentation and is outlined in Table 4.

Table 4.

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| Differential diagnosis of multiple sclerosis |
| Optic neuritis/neuropathy |
| Inflammatory, neuromyelitis optica (NMO) spectrum disorder, genetic, ischemic |
| Myelitis/myelopathy— |
| Inflammatory demyelination—idiopathic, post-viral, post-vaccinialNMO  spectrum disorderAutoimmune--systemic lupus erythematosus, anti-  phospholipid antibody syndrome, other systemic autoimmune disorders |
| Infectious (Lyme disease, HIV, viral, others) |
| Ischemic/vascular |
| Others--compressive, nutritional |
| Brainstem syndrome |
| Stroke, tumor, vasculitis (lupus, Sjögren’s syndrome, Behçet’s disease) |
| Cerebral white matter lesions |
| Small vessel disease (Leukoaraiosis) |
| Migraine |
| Primary CNS vasculitis |
| Sarcoidosis |
| CADASIL (Cerebral Autosomal Dominant Arteriopathy with Subcortical Infarcts  and Leukoencephalopathy) |

### Atypical presentation or variants of MS:

There are some less common clinical variants of MS which present with atypical clinical and radiological features, these include tumefactive MS, Balo’s concentric sclerosis, and Marburg disease. The radiological hallmark of tumefactive MS is a large solitary >2 cm lesion associated with mass effect, edema and/or ring enhancement (hence the name tumefactive). The clinical symptoms depend on the size and location of the lesion and often include aphasia, agnosia, seizures and visual field defects, not typically seen in CIS or RRMS patients (Lucchinetti, et al. 2008). Marburg’s disease and Balo’s concentric sclerosis are characterized by a rapidly evolving fulminant clinical course and poor prognosis. The Marburg variant has the distinct radiological feature of large tumor-like multifocal demyelinating lesions in deep white matter; the pathological changes are similar to those of classicMS but may appear more destructive and have more inflammatory infiltrates (Karussis 2014). The pathological changes seen in Balo’s concentric sclerosis are quite unique and consist of alternating bands of normally myelinated or remyelinated, and demyelinated white matter; this pattern has been described as resembling hypoxia induced injury (Stadelmann, et al. 2005). The MRI may show alternating isointense and hypointense concentric rings with partial enhancement -on T1-weighted images (Zettl, Stüve and Patejdl 2012, Karussis 2014).

## Therapeutic Options

The management of MS includes treatment with immunomodulatory agents that help alter the course of the disease, symptomatic management focusing on relieving specific symptoms such as fatigue, spasticity, bladder dysfunction and pain (not discussed in this review). Corticosteroids (methylprednisolone) and adrenocorticotropic hormone (ACTH) have anti-inflammatory and immunomodulatory effects and are typically used to treat acute relapse to hasten the recovery (Berkovich 2012). The immunomodulatory therapies (IMT) used in long-term disease modification are discussed in the next section.

## Immunomodulatory Therapies (IMT)

The most significant progress in the treatment of MS in the last two decades has been the development of IMT. Since the introduction of first immunomodulating medication, interferon beta-1b in 1993, several other medications with a different mechanism of action, mode and frequency of administration have become available. Currently there are twelve medications approved for treatment of MS, including six self-injectable, three infusion based, and three oral medications as listed in Table 5.

Table 5. Approved Therapies for Multiple Sclerosis

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Medication | Dose | Route | Frequency | Major side effects |
| First line therapies | | | | |
| Beta-interferon-1b (Betaseron®) | 250 mcg | SC | Every other day | Flu-like symptoms, injection site reactions, liver enzyme elevation, thyroid abnormalities, leucopenia or anemia, and depression |
| Beta-interferon-1a (Avonex®) | 30 mcg | IM | Once a week |
| Peginterferon beta-1a (Plegridy®) | 125 mcg | SC | Every 14 days |
| Beta-interferon-1a (Rebif®) | 44 mcg | SC | Three times weekly |
| Beta-interferon-1b (Extavia®) | 250 mcg | SC | Every other day |
| Glatiramer acetate (Copaxone®) | 20 mg | SC | Daily | Local injection-site reactions, post-injection reaction (flushing, chest tightness, palpitation, and dyspnea)) and rare lipoatrophy with prolonged use |
| 40 mg | SC | Three times weekly |
| Second line therapies | | | | |
| Natalizumab (Tysabri®) | 300 mg | IV | Every 4 weeks | Hepatotoxicity, infusion reactions, progressive multifocal encephalopathy (PML) |
| Mitoxantrone (Novantrone®) | Weight based dose | IV | Every 3 months | Cardiotoxicity, secondary leukemia |
| Fingolimod (Gilenya®) | 0.5 mg | Oral | Once daily | First dose bradycardia, atrioventricular block, herpes virus infection, macular edema, elevated blood pressure, rare risk of PML |
| Teriflunomide (Aubagio®) | 7 and 14 mg | Oral | Once daily | Hair loss, headache, diarrhea, hepatotoxicity, teratogenicity, increased risk of infections due to lymphopenia |
| Dimethyl fumarate (Tecfidera®) | 240 mg | Oral | Twice daily | GI effects-nausea, diarrhea, abdominal pain, flushing, pruritus, liver enzyme elevation, lymphopenia, rare cases of PML |
| Alemtuzumab (Lemtrada®) | 12 mg or 24 mg | IV | Per day (5 days in year 1, 3 days in year 2) | Serious infusion reactions, secondary autoimmune diseases-thryoiditis, thrombocytopenia, anti-glomerual basement membrane disease, increased risk of malignancies—thyroid cancer, melanoma, lymphoproliferative disorders |

The mechanism of action of IMT used for treatment of MS is broad suppression of the immune response mediated by autoreactive lymphocytes; most of these are effective in relapsing remitting MS where inflammatory demyelination is the primary process (Weinstock-Guttman, et al. 1995, Rudick, et al. 1997, Damal, Stoker and Foley 2013). The goal of these therapies is to reduce the frequency of relapses and number of MRI lesions (new, enlarging and/or enhancing T2 lesions), and slow the disability progression. Most of these agents have shown good efficacy in patients with relapsing remitting MS and clinically isolated syndrome, however, their benefit in patients with progressive disease has been questionable (Filippini, et al. 2013). The mechanism of action and side effect profile of different IMTs are briefly discussed here with the exception of alemtuzumab, the latest medication to be approved for treatment of MS.

## Beta-Interferon

Interferons (IFNs) are endogenous proteins that are involved in immune response against viral and bacterial agents and were the first class of disease modifying agents developed for treatment of MS. The beta-interferons (IFN-*β*) have multiple actions including stabilizing the BBB thereby limiting the entry of T cells into the CNS, modulating T and B cell function, and altering the expression of cytokines (Wee Yong, Chabot, et al., Interferon beta in the treatment of multiple sclerosis: Mechanisms of action 1998, Weber, et al. 1999, Dhib-Jalbut 2002). Several different preparations of IFN- *β* are available and are listed in Table 3. Both IFN- *β*1a and IFN-*β*1b have shown similar efficacy and are considered first line agents for treating patients with relapsing MS and CIS (Rudick, et al. 1997). Although two different trials with IFN- *β*1b showed conflicting results in secondary progressive MS, it may be indicated in patients with continued relapses (Kappos, L.; Weinshenker, B.; Pozzilli, C.; Thompson, A. J.; Dahlke, F.; Beckmann, K.; Polman, C.; McFarland, H.; The European North American Interferon beta-1b in Secondary Progressive Multiple Sclerosis Trial Steering Committees and Independent Advisory 2004).The side effects of beta-interferon include flu-like symptoms, depression, liver enzyme elevation, thyroid abnormalities, leucopenia or anemia, and injection site reactions (Rudick, et al. 1997).

## Glatiramer Acetate

Glatiramer acetate (GA) or Copolymer 1 is a synthetic complex of four amino acids that mimics myelin basic protein (MBP), one of the autoantigens targeted by the T cells. Due to its structural similarity to MBP, GA blocks the formation of myelin reactive T cells and induces GA-specific regulatory T-cell expression and Th2 anti-inflammatory cytokine production (bystander suppression) (Wolinsky 1995, Rudick, et al. 1997, Gran, et al. 2000, Dhib-Jalbut 2002, Ruggieri, et al. 2007). The clinical efficacy of GA in terms of reducing relapse rate and MRI lesions is similar to IFN-*β*, however, GA has somewhat limited effect on disability progression (Rudick, et al. 1997, La Mantia, Munari and Lovati 2010). The side effect profile of GA is however more favorable and includes local injection-site reactions, post-injection reaction (flushing, chest tightness, palpitation, and dyspnea within minutes of injection with spontaneous resolution) and rare lipoatrophy with prolonged use.

## Natalizumab

Natalizumab is a humanized monoclonal antibody that binds *α*4*β*1-integrin on lymphocytes blocking their interaction with VCAM-1 on endothelial cells thereby preventing the transmigration of lymphocytes across the BBB (Ransohoff 2007) . Its superior efficacy has been demonstrated in two phase 3 studies with a robust effect on relapse rate reduction and disability progression (Miller, Khan, et al. 2003, Polman, O'Connor, et al. 2006) . The major safety concern with natalizumab is progressive multifocal leukoencephalopathy (PML), a serious potentially fatal opportunistic brain infection caused by reactivation of JC virus (Yousry, et al. 2006). As of December 2014, 514 cases of PML have been reported worldwide with post marketing use of natalizumab (TYSABRI® (natalizumab): PML Incidence in Patients Receiving TYSABRI 2014). The overall risk of PML in MS patients with natalizumab use is 3.78 per 1000 with a much higher risk (13/1000) among patients with prolonged duration of therapy (≥ 24 months), history of prior immunosuppressive therapy, and positive JC-virus antibody status (Bloomgren, et al. 2012, TYSABRI® (natalizumab): PML Incidence in Patients Receiving TYSABRI 2014). Due to the risk of PML, natalizumab now has a more limited use as a second line drug in patients with breakthrough disease or intolerable side effects with first line therapies.

## Mitoxantrone

Mitoxantrone is a synthetic anthracendione antineoplastic agent; its immunomodulatory effects include suppression of T and B lymphocytes and macrophage proliferation. Mitoxantrone is indicated for reducing disability and relapse frequency in patients with worsening relapsing-remitting and secondary-progressive MS, however, its use has been limited due to risk of dose related cardiotoxicity and treatment related leukemia (E. J. Fox 2006).

## Oral Therapies

Three new oral medications have recently become available for treatment of relapsing MS: fingolimod, teriflunomide, and dimethylfumarate. The efficacy of these medications has been established in several phase 3 studies with comparable or somewhat better effect (compared to some injectable therapies) on relapse rate reduction, MRI lesions, and disability progression.

*Fingolimod* is a sphingosine-1-phosphate receptor (S1P1) modulator and was the first oral drug approved for treatment of MS. By binding to S1P1 receptor on the T cells, it prevents emigration of activated T cells from lymph nodes thereby limiting their entry into the CNS (Pelletier and Hafler 2012, Yanagawa, Masubuchi and Chiba 1998). The potential side effects of fingolimod include first dose bradycardia, atrioventricular block, herpes virus infection, macular edema, elevated blood pressure, and a reported cases of PML (Kappos, et al. 2010, Cohen, et al. 2010, Samson 2013, Calic, et al. 2015) .

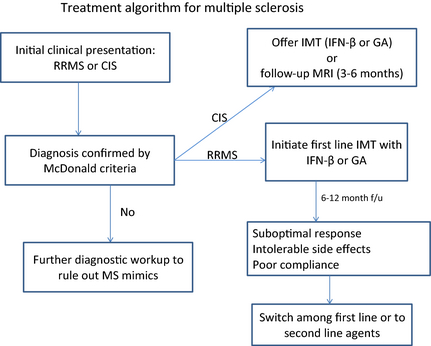
There have been a total of three reported cases of PML associated with use of fingolimod, two of these occurred in context of prior immunosuppressive therapy, the third most recent case however was reported in a patient with no prior immunosuppressive therapy after more than four years of fingolimod use (Calic, et al. 2015, Case of PML reported in patient treated with Gilenya® 2015). A single case of sudden suspected cardiac death within 24 hours of taking first dose of fingolimod was reported in December 2011 (Lindsey, et al. 2012). Even though a direct association with the medication could not be established, the US Food and Drug Administration and European regulatory agency released new monitoring guidelines for first dose monitoring and the drug is now contraindicated in patients with history of cardiac disease or stroke and patients on antiarrhythmic medications.

*Teriflunomide* is an active metabolite of leflunomide (a drug used to treat rheumatoid arthritis) and is an inhibitor of enzyme dihyrdro-orotate dehydrogenase (DHODH) which interferes with denovo synthesis of pyrimidine in rapidly dividing cells (Oh and O'Connor 2013). Its anti-inflammatory effect in MS is believed to be mediated by reducing the activity of proliferating T and B lymphocytes. Teriflunomide does not affect the resting or slowly dividing hematopoietic cells which use the alternate DHODH independent “salvage pathway” for pyrimidine synthesis, therefore, preserving the basic homeostatic functions of these cells and immune surveillance (Oh and O'Connor 2013). Leflunomide is converted almost entirely into teriflunomide after absorption and taken at the recommended doses, both drugs result in similar plasma concentration of teriflunomide (AUBAGIO® (teriflunomide) Prescibing information 2014). The short term side effects of teriflunomide are relatively mild and include hair loss, headache, diarrhea, and elevated liver enzymes.103 Reduction in lymphocyte and neutrophil counts, elevated blood pressure, and a single case of latent tuberculosis are some of the other side effects reported (O'Connor, et al. 2011, Confavreux, et al. 2014). The potential teratogenecity of teriflunomide remains a major concern although several pregnancies reported during its clinical trial did not have any adverse outcome. Nevertheless, strict contraception is recommended to avoid pregnancy and a rapid elimination process is undertaken in women who become pregnant while taking teriflunomide as the drug can remain in the systems for 8 months to two years (Confavreux, et al. 2014).

*Dimethylfumarate (DMF) or BG12* is the latest oral therapy to be approved for treatment of MS. Related to fumaric acid ester which has been used for treatment of psoriasis in Germany since 1990s; BG12 is as an enteric coated formulation of DMF with improved GI tolerability. It is hydrolyzed to monomethyl fumarate soon after oral absorption. The mechanism of action of DMF involves inhibition of proinflammatory pathways via activation of nuclear factor erythroid 2-related factor 2 (Nrf-2) antioxidant response pathway (Linker, et al. 2011). The most common side effect with DMF include nausea, diarrhea, abdominal pain which can be minimized by taking the medication with food and flushing which can be reduced by aspirin (Gold, Kappos, et al. 2012, Fox, Kita, et al. 2014). Lymphopenia may occur although no increased infection risk was observed in phase 3 studies (Gold, Kappos, et al. 2012, Fox, Miller, et al. 2012). There have been a few cases of PML reported with use of fumaric acid ester formulations in patients with psoriasis with pronounced prolonged lymphopenia being the major risk factor (Ermis, Weis and Schulz 2013, Sweetser, Dawson and Bozic 2013, van Oosten, et al. 2013). There has been a recent report of a fatal case of PML in a patient with multiple sclerosis treated with dimethyl fumarate (FDA Drug Safety Communication: FDA warns about case of rare brain infection PML with MS drug Tecfidera (dimethyl fumarate) 2014). In response to these cases of PML, JC virus antibody testing and close monitoring for lymphopenia has been suggested in patients initiating DMF therapy to improve surveillance.

The oral medications are currently considered second line due to a greater risk of serious side effects making their safety profile less favorable in patients with early and mild disease. The main safety concern with oral medications is the potential for prolonged immunosuppression increasing the risk of serious infections and also malignancies due to altered immune surveillance. A simplified treatment algorithm for patients with RRMS and CIS is outlined in Figure 3.

Figure 3. Treatment approach to patients with RRMS and CIS.



In summary, there has been significant progress in the field of MS with better understanding of immunopathogenesis, wider availability and use of MRI, and availability of disease modifying therapies. There are currently a wide range of therapeutic options to treat MS including the recently approved oral drugs. However, balancing the safety and efficacy of these drugs remains a challenge due to serious side effects associated with more effective therapies. Given the heterogeneity of MS, personalized treatment by recognizing specific genetic markers in individual patients has been proposed. Also, there is an urgent need for novel therapeutic agents that can prevent or minimize the neuronal and/or axonal degeneration occurring in patients with progressive MS.

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3. Gadolinium enhancement of lesions is not required for DIS. [↑](#footnote-ref-3)
4. If a subject has a brainstem or spinal cord syndrome, the symptomatic lesions are exclued from the Criteria and do not contribute to lesion count. [↑](#footnote-ref-4)