"Natalizumab treatment for multiple sclerosis: updated recommendations for patient selection and monitoring."

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ABSTRACT

Natalizumab, a highly specific α4-integrin antagonist, is approved for treatment of patients with active relapsing-remitting multiple sclerosis (RRMS). It is generally recommended for individuals who have not responded to a currently available first-line disease-modifying therapy or who have very active disease. The expected benefits of natalizumab treatment have to be weighed against risks, especially the rare but serious adverse event of progressive multifocal leukoencephalopathy. In this Review, we revisit and update previous recommendations on natalizumab for treatment of patients with RRMS, based on additional long-term follow-up of clinical studies and post-marketing observations, including appropriate patient selection and management recommendations.

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Natalizumab treatment for multiple sclerosis: updated recommendations for patient selection and monitoring


Natalizumab, a highly specific α4-integrin antagonist, is approved for treatment of patients with active relapsing-remitting multiple sclerosis (RRMS). It is generally recommended for individuals who have not responded to a currently available first-line disease-modifying therapy or who have very active disease. The expected benefits of natalizumab treatment have to be weighed against risks, especially the rare but serious adverse event of progressive multifocal leukoencephalopathy. In this Review, we revisit and update previous recommendations on natalizumab for treatment of patients with RRMS, based on additional long-term follow-up of clinical studies and post-marketing observations, including appropriate patient selection and management recommendations.

Introduction

Natalizumab—an α4-integrin antagonist—was approved for treatment of patients with multiple sclerosis (MS) who have the active relapsing-remitting form of disease (RRMS) on the basis of its targeted mode of action and its positive effects on various clinical and MRI outcomes in the placebo-controlled clinical studies AFFIRM (Natalizumab Safety and Efficacy in Relapsing-Remitting MS),1–4 SENTINEL (Safety and Efficacy of Natalizumab in Combination with Avonex [IFNβ-1a] in Patients with Relapsing-Remitting MS),4 and GLANCE (Clarithrmer Acetate and Natalizumab Combination Evaluation).5 Natalizumab is generally recommended for individuals who have not responded to currently available first-line disease-modifying therapy or who have very active disease.

Commercial and clinical trial dosing of natalizumab was suspended voluntarily in February, 2005, after three reports were made of progressive multifocal leukoencephalopathy (PML), an often fatal viral disease characterised by progressive inflammation and damage to the white matter, in patients treated with this agent. However, the drug was reintroduced in the USA and approved in the European Union (EU) in June, 2006, after no additional cases of PML were identified in previously treated individuals.6

On the basis of additional analyses of AFFIRM, SENTINEL, and GLANCE, including long-term follow-up and post-marketing observations, we revisit our previous Review7 of the position of natalizumab for treatment of patients with RRMS. We need to consider the conditions of use that are most likely to maintain or increase the therapeutic benefit of natalizumab while minimising patients’ risk. Important factors to consider include appropriate patient selection, routine safety monitoring, and an understanding of both early recognition and timely management of PML. In this Review, we will provide general safety monitoring recommendations and a detailed update to our previous guidelines on the diagnosis and management of PML in natalizumab-treated patients,8 as developed by panels of experts in neurology and neuroradiology.

Natalizumab use and safety

In the 2-year, phase 3 AFFIRM study,1 natalizumab monotherapy significantly decreased annual relapse rates by 68% (p<0·001) in patients with MS and lowered disability progression rates (sustained for 3 months) by 42% (p<0·001) compared with placebo. Additional analyses showed that over 2 years, natalizumab monotherapy elicited a 54% reduction in 6 months’ confirmed disability progression, a 92% decline in the number of gadolinium-enhancing lesions during the second year (p<0·001), an 83% decrease in the number of new or enlarging T2-hyperintense lesions over 2 years (p<0·001), and a 76% fall in new T1-hypointense lesions. Natalizumab also reduced brain atrophy during the second year of treatment.1,11 In subgroup analyses, this drug was also effective in patients with more severe disease.12 Post-hoc investigations indicated that natalizumab substantially raised the probability that individuals were free of disease activity5 and that, in those with a baseline expanded disability status scale (EDSS) score of 2·0 or greater, treatment significantly increased the cumulative probability of 12-week confirmed improvement in disability.9,10 Natalizumab has also been shown to have beneficial effects on visual function1 and several aspects of quality of life.1 Finally, the AFFIRM researchers noted that natalizumab monotherapy was generally safe and well tolerated.11

In the SENTINEL study,7 over 2 years, natalizumab plus interferon beta-1a significantly reduced the cumulative probability of 12-week confirmed disability progression by 24% (p=0·02) and decreased annual relapse rates by 55% compared with interferon beta-1a alone (p<0·001).12 In the phase 2 GLANCE study,13 a 74% lower number of new gadolinium-enhancing lesions (p=0·020) and a 61% decline in new or newly enlarging T2-hyperintense lesions (p=0·029) was recorded with the
Review

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combination of natalizumab plus glatiramer acetate versus glatiramer acetate alone.

Safety data on natalizumab use in the post-marketing setting were available from spontaneous sources and through formal registries and observational studies. As of March 31, 2011, about 83300 patients worldwide had been exposed to natalizumab in the post-marketing setting (representing 148 000 patient-years of exposure), including roughly 55 100 who were exposed for 12 months or longer, 44 900 for 18 months or more, 35 400 for at least 24 months, 27 400 for 30 months or longer, 18 700 for 36 months or more, and 10 700 for at least 42 months.11

On market reintroduction, patients from AFFIRM,1 SENTINEL,9 and GLANCE10 were eligible to participate in an ongoing open-label study (STRATA [Safety of TYSABRI Re-dosing and Treatment])14 undertaken to assess the safety and efficacy of re-exposure to natalizumab after interrupted treatment. Although recurrence of MRI findings and relapse activity was seen during treatment interruption, 1094 patients re-exposed to natalizumab and included in the ongoing STRATA study had low annual relapse rates and either stable or improved EDSS scores over a 120-week treatment period.15,16 The STRATA study did not raise any immediate safety or tolerability concerns in individuals switching from interferons, glatiramer acetate, or chronic steroids to natalizumab, and no patients developed PML during the initial 24–48 weeks of evaluation.17,18 However, four cases of PML were recorded during the long-term treatment period of STRATA (after 33, 34, 44, and 46 cumulative doses of natalizumab), with three of the four patients having received previous immunosuppressive treatment.19 Serum samples available from these individuals, obtained 22–30 months before PML diagnosis, were analysed for the presence of antibodies against JC virus (JCV) with a novel two-step assay that combined standard ELISA with an immunosorbent step. All four patients were identified as being positive for anti-JCV antibodies.32 In STRATA, although overall incidence of infusion and hypersensitivity reactions was low (<1%), it was highest in individuals who had received only one to two natalizumab infusions before treatment interruption and who were also persistently positive for antibodies against natalizumab on subsequent entry into STRATA.20 As a whole, data from the AFFIRM open-label safety-extension study33 and the ongoing STRATA long-term study support the continued efficacy of natalizumab monotherapy over 3 years of treatment.14

Compared with the closely regulated conditions of clinical trials, the broader world of clinical practice could show greater variability in patients’ characteristics. Whereas the AFFIRM1 study population consisted largely of patients with MS who were treatment-naive, people treated with natalizumab in the clinical practice setting generally have more severe disease at baseline and most have received other disease-modifying therapies before natalizumab. Thus, to continue to assess the safety profile of natalizumab in clinical practice, a comprehensive risk-management plan was developed, including the TOUCH (Tysabri Outreach: Unified Commitment to Health) prescribing programme, mandatory in the USA, and the TYGRIS (Tysabri Global Observation Program in Safety) study. As of June 30, 2010, 42 587 patients with MS were enrolled and 37 048 had received natalizumab in TOUCH,20 and as of May 23, 2010, 6467 patients were enrolled in TYGRIS,13 with 2203 in the USA and 4264 in the rest of the world. Several study groups have reported on their experience with natalizumab in clinical practice, with data from these observational studies and registries indicating similar efficacy and tolerability of natalizumab as have been reported for clinical studies.21–28

The overall incidence of serious adverse events associated with natalizumab treatment seems to be low. Although spontaneous cases of serious liver injury (eg, strikingly raised amounts of hepatic enzymes or hyperbilirubinaemia) could potentially arise after natalizumab treatment, particularly in patients with pre-existing hepatic disorders, these adverse events have been recorded only rarely in the post-marketing setting.29,30 The rate of potentially serious liver events noted thus far has been similar in the placebo and treatment arms of clinical studies of natalizumab. Cases of melanoma have been seen in women with MS treated with natalizumab.31,32 However, a meta-analysis of safety data from clinical studies showed that the incidence of melanoma was similar in those who received natalizumab and placebo (0.07% vs 0.10%), corresponding to melanoma rates of 0.419 vs 0.823 per 1000 patient-years).33 CNS lymphoma has also been reported;24–26 two patients diagnosed after one and three doses of natalizumab, respectively, had pre-existing disease that seems to have been unrelated to natalizumab.11 Another case of CNS lymphoma that arose after 22 doses of natalizumab was reported in a patient negative for Epstein-Barr virus antibodies,34 which are typically present in immunosuppression-related CNS lymphoma. Delayed infusion reactions (>2 h after natalizumab infusion), including type 3 serum sickness reactions managed with short courses of corticosteroids, are rare but have been noted.24–26 Finally, in clinical trials, herpes infections (varicella zoster and herpes simplex) occurred slightly more frequently in natalizumab-treated patients than in those receiving placebo. In post-marketing experience, rare reports have been made of serious herpes infections, including one fatal case of herpes encephalitis.24–26

Background on PML

PML is an opportunistic infection of the CNS that, in cases unrelated to natalizumab, usually leads to death or severe disability.35 Active replication of the human polyoma JCV in glial cells of the brain, causing lytic
death in oligodendrocytes, is the underlying pathobiology of PML. The infection typically arises in severely immunocompromised patients—eg, those with HIV infection, malignant disease, or transplanted organs. Development of PML is extremely rare in immunocompetent individuals. People with autoimmune rheumatic diseases, especially systemic lupus erythematosus, are also at higher risk of PML. Administration of immunosuppressive treatments to any of these high-risk populations could further increase the likelihood of developing PML. In addition to natalizumab, cases of PML have been reported in patients treated with various drugs, usually in combination with corticosteroids, including alkylating agents (eg, cyclophosphamide, carmustine, and dacarbazine), purine analogues (eg, fludarabine, cladribine, and azathioprine), immunosuppressants (eg, ciclosporin, tacrolimus, sirolimus, and mycophenolate), and therapeutic monoclonal antibodies (eg, rituximab, infliximab, etanercept, basiliximab, daclizumab, efalizumab, alemtuzumab, and muromonab-CD3).

![Figure 1: Estimated PML incidence by natalizumab treatment duration (A) and treatment epoch (B)](image)

(A) Incidence by treatment duration was calculated from natalizumab exposure data up to May 31, 2011, and 133 confirmed cases as of June 1, 2011. Incidence for each period was calculated as number of PML cases arising after a defined minimum number of infusions divided by number of patients exposed to natalizumab (eg, for ≥24 infusions, all PML cases diagnosed after exposure to 24 infusions or more divided by the total number of patients ever exposed to at least 24 infusions).

(B) Incidence for each treatment interval was calculated as number of PML cases arising during a treatment interval divided by number of patients exposed to natalizumab (eg, for 25–36 infusions, number of all PML cases diagnosed during this treatment interval divided by total number of patients ever exposed to at least 25 infusions). PML=progressive multifocal leukoencephalopathy. Error bars=95% CI. *Observed clinical trial rate in patients who received a mean of 17.9 monthly doses of natalizumab.
in the TYGRIS observational study as of Nov 23, 2010. PML = progressive multifocal leukoencephalopathy.

Previous immunosuppressant use are based on frequency of immunosuppressant use before natalizumab treatment with confirmed PML as of March 4, 2011, of whom only 93 have available data for immunosuppressant use. Data for previous immunosuppressant use are based on frequency of immunosuppressant use before natalizumab treatment in the TYGRIS observational study as of Nov 23, 2010. PML = progressive multifocal leukoencephalopathy.

Figure 2: Approximate incidence of PML stratified by previous immunosuppressant use and duration of natalizumab treatment

Data are up to Feb 28, 2011. Data for PML incidence and previous immunosuppressant use are based on 102 patients with confirmed PML as of March 4, 2011, of whom only 93 have available data for immunosuppressant use. Data for previous immunosuppressant use are based on frequency of immunosuppressant use before natalizumab treatment in the TYGRIS observational study as of Nov 23, 2010. PML = progressive multifocal leukoencephalopathy.

PML in natalizumab-treated patients

PML was identified in three patients (two with MS and one with Crohn’s disease) from pre-marketing clinical studies.44-46 As of June 1, 2011, all 133 reported cases of PML since relaunch of natalizumab (USA [n=50], European Economic Area [76], and rest of the world [7]) arose in people with MS who had received natalizumab monotherapy for more than 1 year.11 As of May 4, 2011, on the basis of post-marketing reports, the estimated overall risk of PML is 1·51 per 1000 patients (95% CI 1·27–1·79), which is generally similar to rates seen in clinical trials (figure 1).11

Analyses pertaining to the first 79 post-marketing cases (reported up to Dec 2, 2010)44-46,47 are outlined below. Overall recommendations, including presenting symptoms and management, are based on a cumulative review of 68 cases. 35 patients aged 27–59 years (mean 43.7) developed PML; 71% were women. Available details about the first 68 cases since relaunch are provided in the webappendix (pp 1–2). Mean number of doses of natalizumab received was 26–60 (range 12–44). At presentation, cognitive or behavioural symptoms were noted most usually, either alone or in association with motor, language, or visual symptoms. MRI findings at the time PML was suspected showed typical subcortical lesions. 43% of MRIs had some gadolinium enhancement, which was usually less intense and more granular or punctate than that typically seen with MS lesions. Nearly all cases were confirmed as PML on the basis of detection of JCV in the CSF. Levels of JCV detected were often low (<500 copies per mL, with 11 copies per mL the lowest detected level and 626 copies per mL the median).

Duration of natalizumab dosing before PML diagnosis ranged from about 1 year to more than 3·5 years (mean 2 years). Incidence of PML over time (figure 1) was very low in the first 12 months of treatment but thereafter increased up to 36 months.11 Data currently available do not permit calculation of whether risk continues to rise after this period. If PML is more likely to develop after 12 months of treatment, the number of patients potentially at risk who have received natalizumab for 12 months or more (based on worldwide post-marketing data) is about 55 100.11 Risk of PML by treatment epoch (figure 1) rose in individuals with more than 24 months of natalizumab exposure, as calculated from cumulative exposure, including those receiving the drug in clinical trials (post reintroduction) and combined worldwide post-marketing exposure up to May 31, 2011.11

Patients with MS who developed PML were more likely to have been treated with an immunosuppressant before receiving natalizumab compared with the overall natalizumab-treated population. Immunosuppressant use at any time before initiation of natalizumab treatment increases risk of developing PML, despite there being no evidence for residual immune suppression when natalizumab treatment was initiated. As of March 4, 2011, 42% (39/93) of people with PML had been treated with an immunosuppressant before receiving natalizumab (previous use of an immunosuppressant was unknown for nine patients, who were excluded from analysis), but, at present, no specific pattern in type or duration of immunosuppressant use has been identified.11 By comparison, in TYGRIS, about 20% of natalizumab-treated patients (14% in the USA and 24% in Europe) had been treated with an immunosuppressant before receiving natalizumab.11 On the basis of these figures, individuals who have used immunosuppressants previously have about a 3–4-times greater risk of PML compared with those who have not used these drugs before.11 The increased risk of PML with previous immunosuppressant use seems to be independent of PML risk associated with duration of natalizumab treatment. As of Feb 28, 2011, PML risk for those who have not used immunosuppressants previously was estimated at 0·19 per 1000 patients (95% CI 0·10–0·33) with 1–24 months of natalizumab treatment and 1·37 per 1000 patients (95% CI 0·97–1·90) exposed for 25–48 months. Risk of PML in individuals with previous exposure to immunosuppressants was 0·66 per 1000 patients (0·32–1·20) with 1–24 months of natalizumab treatment and 4·30 per 1000 patients (2·90–6·20) exposed for 25–48 months (figure 2).11 Estimates of PML risk in people with previous use of immunosuppressants have limitations; they are based, in part, on the proportion of patients in TYGRIS who have used immunosuppressants before, which is only a small subset of the overall natalizumab-treated population and, therefore, might not be representative of the entire population. Risk stratification by previous immunosuppressant use and treatment duration must be considered in a broader context that includes additional factors such as benefits of treatment, risks of inadequately treated MS, and the relative benefit–risk profiles of alternative treatments.
Discontinuation of natalizumab is recommended on first suspicion of signs, symptoms, or MRI findings, or a combination, compatible with PML.\textsuperscript{51,52,53} Nearly all patients with PML have undergone plasma exchange or immunoadsorption to more rapidly remove natalizumab from plasma and to speed reconstitution of immune surveillance.

As of June 1, 2011, 24 of 133 (18%) natalizumab-treated patients with PML had died. The 109 surviving individuals have varying levels of disability, ranging from mild to severe.\textsuperscript{14} On the basis of preliminary data gathered from the first 79 cases of PML since relaunch of natalizumab, of people who were alive, had at least 6 months of follow-up after diagnosis of PML, and had Karnofsky scores\textsuperscript{84} available (33 of 63 patients), 13% had mild disability, 50% had moderate disability, and 37% had severe disability.\textsuperscript{15} It is still too early to draw broad conclusions about outcomes in patients who developed PML while on natalizumab treatment.\textsuperscript{11,13} Data are currently insufficient to predict risk factors for PML survival and disability outcomes. Preliminary findings suggest that a delay in PML diagnosis and widespread changes typical of PML on MRI are associated with worse prognosis. High-dose steroid treatment, which is frequently used to combat the reversible inflammation associated with immune reconstitution inflammatory syndrome (IRIS), does not seem to be associated with increased mortality and is advocated by many experts.\textsuperscript{50,51} Outcomes of natalizumab-treated patients with PML are generally better than those recorded in clinical trials or reported in other settings (eg, HIV).\textsuperscript{11} Overall, these data support heightened clinical vigilance, early PML diagnosis, and cessation of natalizumab treatment on suspicion of PML to optimise outcomes for patients with MS.

A laboratory marker that predicts the likelihood of PML development is needed urgently for selection of people most likely to benefit safely from natalizumab treatment and for early detection of PML. Despite one report of asymptomatic reactivation of JCV in a patient treated with natalizumab,\textsuperscript{16} analysis of blood and urine samples from nearly 1400 individuals participating in clinical studies of natalizumab showed that JCV DNA was found rarely in blood. In the few cases in which JCV viraemia was recorded, no association was seen with natalizumab treatment or development of PML. Patients who developed PML related to natalizumab treatment also tested negative for JCV DNA in blood and peripheral blood mononuclear cells before onset of symptoms.\textsuperscript{85} Blood analyses for raised amounts of CD34+ cells and JCV DNA have been suggested as useful for early detection,\textsuperscript{86} but a recent publication casts some doubt on the robustness of this approach.\textsuperscript{87}

A two-step anti-JCV antibody assay that combines ELISA with an immunoadsorption step has been developed and is currently undergoing clinical evaluation. Preliminary assessments detected anti-JCV antibodies in 54% of patients with MS who were tested.\textsuperscript{88}

Anti-JCV antibody status seems to be stable over time, with an annual seroconversion rate that does not exceed 2–3%.\textsuperscript{89} With this assay, assessment of anti-JCV antibodies in archived serum samples obtained from 31 natalizumab-treated patients 6–187 months before PML diagnosis showed that samples from all 31 patients tested positive for anti-JCV antibodies. For patients who were positive for anti-JCV antibodies and had not used immunosuppressants before, irrespective of treatment duration, PML risk was consistent with risk in the overall natalizumab-treated population.\textsuperscript{86} *Estimate based on all patients negative for anti-JCV antibodies receiving at least one dose of natalizumab and one hypothetical PML case who was negative for anti-JCV antibodies at the time of PML diagnosis. †PML incidence in patients positive for anti-JCV antibodies calculated on the basis of the following assumptions: 55% of natalizumab-treated patients with multiple sclerosis are positive for anti-JCV antibodies, the proportion of natalizumab-treated patients with previous immunosuppressant use was 20% based on data from TYGRIS, and 100% of confirmed cases of PML were positive for anti-JCV antibodies before onset and diagnosis of PML. Data are risk per 1000 patients (95% CI).

PML risk management

Plans for risk management of PML for patients with MS have been instituted in the EU, the USA, and elsewhere. In the EU, prescription of natalizumab is restricted to doctors skilled in the treatment of neurological diseases who have timely access to MRI facilities and have the ability to manage hypersensitivity reactions.\textsuperscript{90} Specific education of doctors with respect to management of PML is needed for all prescribers, and
patients with MS are issued with a special card describing the possible symptoms of PML and other infections needing immediate investigation. In the USA, the TOUCH prescribing programme restricts distribution, prescription, and administration of natalizumab to registered pharmacies, doctors, and infusion centres, and provides guidelines for monitoring of patients with MS for PML and other potential serious adverse events.

**Diagnostic algorithm**

Clinical vigilance is the most important way to spot PML. The history and pattern of previous and current symptoms and signs will facilitate both patient management and assessment of potential PML (panel). If PML is suspected, neurologists should withhold natalizumab until this disease can be excluded. If a thorough neurological assessment cannot rule out PML, natalizumab must be suspended and not restarted until a disorder other than MS has been excluded with confidence. Natalizumab dosing can be resumed only if the diagnosis of PML is discounted. If PML is confirmed, permanent discontinuation of natalizumab is a key intervention.

Several PML diagnostic assessments in individuals treated with natalizumab are recommended. First, a thorough neurological assessment should be undertaken at first presentation of new or worsening clinical signs or symptoms (figure 4). Second, if neurological assessment cannot rule out PML, cranial MRI with contrast should be done and compared with previous MRI scans; to optimise comparability, standardised high-quality imaging should be obtained at treatment start and at yearly intervals. MRI alone cannot be used to exclude PML (figure 5, table). If clinical symptoms or MRI lesions remain suggestive of PML, testing of CSF by PCR for JCV DNA—with an ultra-sensitive assay—should be done. Repeat MRI is recommended if clinical suspicion of PML remains. CSF can be negative for JCV DNA in early PML despite clinical and radiographic findings. If JCV is not detected but suspicion of PML persists, a repeat CSF test is recommended and—if it is again negative—a brain biopsy procedure should be considered (figure 6). Detection of JCV DNA in the CSF of a symptomatic patient confirms the diagnosis. However, a negative JCV PCR result should not exclude a possible diagnosis of PML. The JCV DNA assay should be based on quantitative real-time PCR to maximise sensitivity and specificity for detection, and an assay with a maximum lower limit of quantification of 50 DNA copies per mL should be used.

**Patient management**

At present, immune reconstitution (restoration of normal immune function or normal access to the brain for immune surveillance) is the only intervention that is effective for PML. Therefore, natalizumab-associated PML differs from PML associated with other disorders in that immune surveillance can be restored within a few weeks. Data from an open-label study in patients with MS receiving natalizumab.
MS showed that plasma exchange rapidly reduced amounts of natalizumab in serum and restored leukocyte function, suggesting its potential value in facilitating immune reconstitution in cases of PML. Several courses of plasma exchange or immunoabsorption were used in post-marketing cases of PML to accelerate clearance of natalizumab from the circulation and to enhance immune surveillance of the CNS. Findings of small studies and retrospective observations show that antiretroviral treatments, serotonin 5-HT2A-receptor antagonists, and immunomodulatory therapies (interleukin 2 or interferon alfa or beta) for management of PML associated with HIV or transplantation are not effective. Mefloquine has been evaluated as a potential anti-JCV agent for treatment of PML and was administered to some patients with post-marketing natalizumab-associated PML, but to date, no clinical report has been published of demonstrable activity against JCV in vivo. Use of the investigational compound CMX001, an oral lipophilic nucleotide analogue of the antiviral cidofovir, in conjunction with plasma exchange, high-dose corticosteroids, intravenous immunoglobulin, and neurehabilitation, was associated with stabilisation and recovery from PML that had developed in a natalizumab-treated MS patient.

**Immune reconstitution inflammatory syndrome**
PML develops in people with immunodeficiency but its characteristics can change with reconstitution of the immune system. IRIS arises with immune reconstitution, and is characterised by a striking lymphocytic response—usually with a predominance of CD8+ lymphocytes—and develops in correlation with control of JCV, tissue swelling, and breakdown of the blood–brain barrier, resulting in gadolinium contrast enhancement on scans. PML in natalizumab-treated patients with MS has been particularly associated (more than previously seen with other diseases) with inflammatory transformation of brain lesions, probably because the immune system is intact, and the effects of the drug can be reversed. This inflammation results in an improved outlook for control of JCV while causing associated inflammatory damage in the brain. Effective immune reconstitution with minimum associated inflammatory neurological injury is necessary for management of PML in this setting, when an inflammatory reaction is typical.

In the post-marketing setting, nearly all patients with PML underwent plasma exchange or immunoabsorption to remove natalizumab from the plasma, to speed reconstitution of immune surveillance. IRIS developed about 2–12 weeks (mean 4–2 weeks) after cessation of natalizumab and earlier than this time (a few days to 8 weeks) in patients who underwent plasma exchange. With IRIS, affected individuals generally presented with striking deterioration of neurological symptoms, which in some was associated with new or enhanced lesions on gadolinium-contrast MRI, brain swelling, or both. In most people in whom IRIS was diagnosed, treatment with high-dose steroids was initiated and led to improvements. For patients with MS who develop PML while on natalizumab, stopping this drug will reconstitute CNS immunity and will probably precipitate IRIS. If natalizumab is removed from the circulation by plasma exchange or immunoabsorption, the disorder will arise more rapidly and, by inference, PML will be brought under control more quickly. It is not clear whether IRIS becomes more manageable with use of plasma exchange or immunoabsorption. Corticosteroids could be useful for treatment of IRIS, particularly in severe or life-threatening cases of the disorder. In support of this approach, early treatment with steroids in patients with HIV who developed IRIS improved prognosis, and steroids probably control the cerebral oedema associated with IRIS. However, diagnosis and management of
Findings suggest a typical target-like lesion pattern on diffusion-weighted images (DWI), with increased DWI contrast leukoencephalopathy. FLAIR = fluid-attenuated inversion recovery. *No MRI features are pathognomonic of MS or PML.**

**Table: MRI features for differential diagnosis of MS and PML**

<table>
<thead>
<tr>
<th>Aspect and location of new lesions</th>
<th>MS</th>
<th>PML</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mostly focal, might affect entire brain and spinal cord, in white and possibly grey matter</td>
<td>Mostly focal, might affect entire brain and spinal cord, in white and possibly grey matter</td>
<td>Diffuse and asymmetric lesions (initially sometimes unifocal but usually multifocal or widespread), mainly subcortical and rarely periventricular, located almost exclusively in white matter, with occasional extension to deep grey matter, posterior fossa frequently involved (cerebellum, brainstem), rarely in spinal cord</td>
</tr>
<tr>
<td>Borders</td>
<td>Sharp edges, mostly round or finger-like in shape (especially periventricular lesions), confluent with other lesions; U-fibres might be involved</td>
<td>Ill-defined edges, infiltrating, irregular in shape; confined to white matter, sparing grey matter; pushing against the cerebral cortex; U-fibres destroyed; typical spread along white-matter tracts</td>
</tr>
<tr>
<td>Mode of extension</td>
<td>Initially focal; lesions enlarge within days or weeks and decrease in size within months</td>
<td>Lesions extend homogeneously, continuously, and sometimes rapidly to contiguous (multifocal) and non-contiguous regions (widespread); confined to white-matter tracks, sparing the cortex</td>
</tr>
<tr>
<td>Mass effect</td>
<td>Acute lesions show some mass effect</td>
<td>No mass effect even in large lesions (but lesion slightly abuts cerebral cortex), apart from when inflammatory response is present</td>
</tr>
<tr>
<td>On T2-weighted sequence</td>
<td>Acute lesions have a hyperintense centre, isointense ring, and discrete hypointensity outside the ring structure; subcortical and chronic lesions are hyperintense with no ring structure</td>
<td>Acute lesions have a hyperintense centre, isointense ring, and discrete hypointensity outside the ring structure; subcortical and chronic lesions are hyperintense with no ring structure</td>
</tr>
<tr>
<td>On T1-weighted sequence</td>
<td>Acute lesions are densely hypointense (large lesions) or isointense (small lesions); increasing signal intensity over time in 80%; decreasing signal intensity (axonal loss) in about 20%</td>
<td>Slightly hypointense at onset, with signal intensity decreasing over time and along the affected area; no reversion of signal intensity</td>
</tr>
<tr>
<td>On FLAIR sequence</td>
<td>Hyperintense, sharply delineated</td>
<td>Preferred sequence for diagnosis because hypointensity is most obvious; true extension of abnormality more clearly visible than on T2-weighted images, especially in coronal cuts</td>
</tr>
<tr>
<td>With gadolinium enhancement</td>
<td>Acute lesions have dense homogeneous enhancement and sharp edges, and contrast enhancement covers whole extension of the new lesion; subacute lesions have ring enhancement with eventual resolution over 1–2 months; chronic lesions show no enhancement</td>
<td>About half the cases to date have shown some enhancement, typically with a patchy aspect; some peripheral enhancement is possible; enhancement usually increases with inflammatory response or decreases with steroid administration</td>
</tr>
<tr>
<td>Atrophy</td>
<td>Focal atrophy is possible due to focal white-matter degeneration; no progression</td>
<td>Initially no focal atrophy; later in the course atrophy can arise</td>
</tr>
</tbody>
</table>

Table: MRI features for differential diagnosis of MS and PML

IRIS remains controversial because data from controlled studies are sparse, but most experts—partly based on observations in case series—recommend rapid reconstitution of immune surveillance by plasma exchange (three to five sessions of 1·5 volume plasma exchange over 6–12 days)** and anti-inflammatory treatment with steroids as soon as IRIS manifests.

**Treatment interruption**

In patients who developed PML while being treated with natalizumab, the duration of treatment before diagnosis ranged from about 1 year to more than 3·5 years (mean duration 2 years).** As depicted in figure 1, risk of PML increases with longer treatment duration, at least up to 36 months.** Up to now, interruption of natalizumab treatment has not been shown to reduce risk of PML, and event-driven studies to examine the effects of treatment interruptions on PML risk would be very difficult to undertake. Since PML is such a rare adverse event, such a study would need an unrealistically large population and long observation period. Risk of MS relapse after cessation of treatment is increased, although the extent to which disease activity recurs is assumed to depend largely on activity before initiation of any disease-modifying treatment together with disease activity before starting natalizumab.** Relapses were measured over an 8-month period in 1866 patients from clinical studies undertaken after voluntary suspension of natalizumab in February, 2005: gadolinium-enhancing lesions were analysed in 341 patients. Annual relapse rates and gadolinium-enhancing lesions both rose shortly after natalizumab interruption and peaked between 4 and 7 months. A rebound of relapse or gadolinium-enhancing lesion activity beyond placebo-treated levels from the clinical studies was not recorded in any analyses.** None of the patients who had been on continuous treatment for more than 18 months developed de-novo antibodies to natalizumab after re-institution of treatment after interruption. Findings from a small study showed that clinical relapse or new lesions on MRI arose in seven of ten patients within 6 months of treatment discontinuation.** These authors concluded that alternative therapies should be considered during an interruption in natalizumab treatment to minimise resumption of disease activity. The RESTORE study (Randomized Treatment Interruption of Natalizumab)** is in progress to assess the rate of immune reconstitution after treatment interruption, the return of MS disease activity during interruption, and whether alternative therapies control the return of disease activity during interruption of natalizumab treatment. Additionally, efforts are underway to investigate the feasibility of alternative dosing regimens. However, at this time, neurologists treating patients with MS with natalizumab should expect and inform individuals that MS disease activity will return if an interruption period is initiated. When reviewing the collective body of data, treating doctors should also recognise that a patient’s true baseline level of disease activity might not be known because of residual effects of treatments used before initiation of natalizumab.

**Natalizumab treatment recommendations Patient selection**

In the USA, natalizumab is indicated as monotherapy for patients with relapsing forms of MS. Although this
agent is generally recommended for those who have had an inadequate response to—or cannot tolerate—an alternative MS treatment, the US label also allows use of natalizumab as first-line therapy in individuals with relapsing MS, and as a result, US patients with progressive relapsing MS are more frequently treated with natalizumab. In a re-evaluation by the European Medicines Agency, no reason existed to change current natalizumab indications as a monotherapy to delay accumulation of physical disability and reduce the frequency of clinical exacerbations in patients with RRMS not responding to first-line disease-modifying therapy or presenting with unusually high relapse and MRI activity. Although initial observations of PML arose in two patients with MS treated with a combination of interferon beta-1a and natalizumab, the fact that all subsequent cases of PML in the post-marketing setting occurred in people treated with natalizumab monotherapy suggests that PML risk is not due to interferon beta-1a. The increased risk of PML in immunosuppressed individuals means that natalizumab should not be given in combination with immuno-suppressive treatment. However, as clearly shown by open-label PML cases, avoidance of natalizumab in combination with other disease-modifying treatments does not eliminate risk of PML.

Previous treatment with immunomodulators or immunosuppressants
Experience in pivotal studies and post marketing does not suggest an increased risk of complications—including PML—in patients who switch directly from interferons or glatiramer acetate to natalizumab. Individuals treated previously with interferon beta or glatiramer acetate might switch directly to natalizumab with no washout period as long as any signs of relevant treatment-related abnormalities are resolved. Patients who are HIV-positive and those with a history of immunodeficiency or haematological malignant disease should not receive treatment with natalizumab (data on file, Biogen Idec, MA, USA). Additional considerations for patient selection include other comorbidities, treatment history, and baseline laboratory values, particularly in those who have received previous immunosuppressants. The increased risk of PML emerging from post-marketing experience for patients exposed previously to immunosuppressive agents (eg, mitoxantrone, cyclophosphamide, cladribine, azathioprine, mycophenolate, methotrexate, or a combination) further underlines the need for careful assessment of those previously treated with immunosuppressive or antineoplastic agents for signs or symptoms of ongoing immune compromise before initiation of natalizumab. Such assessment should include normal leukocyte and differential counts, absence of signs of increased infection rate in the months preceding natalizumab treatment, and close clinical monitoring. A washout period of 3–6 months has been proposed for people who have received immunosuppressants. A longer washout period for mitoxantrone and cyclophosphamide is desirable, but the timeframe would need to be weighed

Figure 6: Laboratory differentiation of new or worsening neurological symptoms in patients with MS receiving natalizumab
Natalizumab must be suspended and not restarted until non-MS pathology has been excluded confidently. Clinical findings should be compared with those recorded at clinical presentation of this episode. Close clinical follow-up consists of biweekly assessments. Relapses should be managed according to usual clinical practice. A short course of steroids can be considered for patients in whom PML is unlikely to arise on clinical grounds. No response to steroids should trigger further investigation. Accelerate re-testing if aggressive clinical symptoms persist or progress. Resumption of natalizumab treatment must be considered only once PML or other opportunistic infections have been excluded definitively on the basis of clinical findings, further investigations, or both. Clinicians should consider other non-MS pathology in addition to PML, especially opportunistic infections, or consider brain biopsy to confirm or discount presence of JCV if CSF PCR is negative but if suspicion persists on the basis of clinical and MRI features. MS=multiple sclerosis. PML=progressive multifocal leukoencephalopathy. JCV=JCV virus. IRIS=immune reconstitution inflammatory syndrome.
against the aggressiveness of active disease. Natalizumab probably should be used in patients with active relapsing MS before immunosuppressants, for which evidence of effectiveness is less well established. As of now, no consensus exists about how frequently laboratory testing needs to be done in individuals at increased risk of PML. In addition to thorough clinical assessment at each of the monthly infusions (by interview and as needed by clinical examination), more frequent MRI has been suggested (every 3–6 months).

Management of infusion and hypersensitivity reactions
Infusion centres should be prepared for appropriate management of infusion and hypersensitivity reactions that can arise with natalizumab treatment. Typical symptoms of infusion reactions include headache, dizziness, and nausea and are usually not a reason to stop natalizumab. These symptoms are usually managed by pretreatment with loratidine and paracetamol and by slowing the rate of infusion.8 In the AFFIRM study,1 hypersensitivity reactions were defined as any report of hypersensitivity or allergic reactions, anaphylactic or anaphylactoid reactions, urticaria, allergic dermatitis, or hives. Symptoms of hypersensitivity reactions can also include fever, rash, rigors, pruritus, nausea, flushing, hypotension, dyspnoea, or chest pain. By contrast with infusion reactions, current recommendations for hypersensitivity reactions are for natalizumab treatment to be discontinued and for the individual not to be retreated. Because of the effectiveness of natalizumab, this recommendation needs further investigation. Resumption of treatment after a hypersensitivity reaction is permitted for specific antibody treatments if they are administered in conjunction with pretreatment.12 A French cohort of 70 patients with MS who were pretreated with hydrocortisone and dexchlorpheniramine had no hypersensitivity reactions to natalizumab compared with another group of 384 people who were not pretreated and who had a hypersensitivity rate of 3–6%.3 Persistent antibodies against natalizumab were associated with an increase in infusion-related adverse events in the AFFIRM study.8 For patients having frequent infusion reactions or with reduced efficacy, testing for persistent antibodies could be useful when deciding whether to discontinue natalizumab treatment, although testing before 3–6 months of treatment is not recommended. If patients test positive for antibodies they should be checked again 2–3 months thereafter. Natalizumab treatment does not need to be discontinued in the interim, but if both test results are positive for persistent antibodies against the drug, it should be discontinued. Patients who receive only one or two doses of natalizumab followed by an extended period without treatment might be at higher risk of hypersensitivity reactions on re-exposure,8 and consideration should be given to testing for the presence of antibodies before re-dosing in these individuals.

Delayed hypersensitivity reactions to natalizumab can occur up to 21 days after infusion.7 18 91 Not all reported cases were positive for neutralising antibodies and most people responded to short courses of oral prednisolone. Occurrence of a delayed reaction would warrant antibody testing. If delayed reactions happen in antibody-negative patients, these can be managed with steroids.

Pregnancy
As far as we know, no adequate and well controlled studies of natalizumab treatment have been done in pregnant women. Natalizumab is recommended during pregnancy only if the potential benefit justifies the potential risk to the fetus. The drug has been detected in human milk; the effects of exposure via breastmilk on infants are unknown.70 TPER (Tysabri Pregnancy Exposure Registry) is a follow-up study of pregnant women with MS who were exposed to natalizumab within 3 months of conception or at any time during pregnancy. As of May 23, 2010, a total of 229 pregnant patients were enrolled prospectively into TPER; 172 known pregnancy outcomes were recorded.74 Although pregnancy data are scant, interim analyses do not suggest any effect of natalizumab exposure on pregnancy outcome. Additional data are needed before a definite conclusion can be made.

Educational guidance
Doctors need to inform patients about the benefits and risks of natalizumab, provide them with a patient’s alert card before initiation of treatment, and continue to counsel them on the risk of PML on a regular basis thereafter. Because of the increased risk of development of PML with prolonged treatment duration in JCV antibody-positive patients, the benefits and risks of natalizumab therapy should be reconsidered on an individual basis by the specialist doctor and the patient. The patient should be updated regularly about the risks of natalizumab, especially the amplified risk of PML, and, together with caregivers, should be reminded of early signs and symptoms of this adverse event. Patients should be instructed to contact their health-care provider should signs of liver injury (eg, jaundice, vomiting) arise, and they should be monitored regularly as appropriate for impaired liver function.
Conclusions
Natalizumab has proven a highly effective treatment for patients with RRMS. The decision to prescribe this drug entails a benefit–risk assessment for each individual. The overall risk of PML still seems to be one case per 1000 individuals with MS; risk seems lower in patients who are seronegative for anti-JCV antibodies and higher in those who are JCV antibody-positive with previous immunosuppressive treatment. The clinician and patient must consider disease activity (both in terms of relapses with functional decline and MRI activity) and ascertain the likelihood of disability if natalizumab treatment is not started and balance these factors against the risk of developing PML with this drug. Once treatment is started, regular and comprehensive follow-up is essential. Early diagnosis and aggressive clinical management have probably led to the apparently better outcomes of post-marketing cases of PML compared with those noted in clinical trials or in the setting of systemic immunodeficiency. Ongoing studies and comprehensive, systematic post-marketing surveillance will continue to provide information that will help doctors make informed treatment decisions about natalizumab and further optimise its use in MS treatment.

Contributors
LK and JK interpreted and analysed data obtained in phase 3 core and extension studies and safety follow-up, reviewed published work, summarised discussions from expert groups, prepared a first draft of the Review, and reviewed and edited all drafts. DB, GE, ME, AG-M, NG, H-PH, EH, JH, RH, MK, OL-C, AM, CP, MR, TS, CS, and KV participated in the development of the guidelines and reviewed and approved drafts and the final version of the Review. DBC, SH, PWO'C, HLW, MC, RG, E-WR, and PSS reviewed and helped with final editing of the Review. EOM and HHDD have provided laboratory assays for detection of JCV DNA in clinical samples of patients with multiple sclerosis relevant to the Review and edited the approved final version.

Conflicts of interest
LK discloses that the University Hospital, Basel, has received research support from Actelion, Advancell, Allozyne, BaroFold, Bayer Health Care Pharmaceuticals, Bayer Schering Pharma, Bayhill, Biogen Idec, BioMarin, CLC Behring, Elan, Genmab, Genmark, GeNeuro SA, GlaxoSmithKline, Lilly, Merck Serono, MediciNova, Novartis, Novonordisk, PepTimmune, Sanofi-Aventis, Santhera, Roche, Teva, UCB, and Wyeth. LK has been principal investigator, member, or chair of steering committees or advisory boards on multiple sclerosis clinical trials sponsored by these companies, and has received lecture fees from one or more of these companies. Payments and consultancy fees have been used exclusively for support of research activities. DB has received honoraria and research support from Biogen Idec, Serono, Schering, and Teva Pharmaceuticals. 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