Effect of Anti-CD25 Antibody Daclizumab in the Inhibition of Inflammation and Stabilization of Disease Progression in Multiple Sclerosis

Bibiana Bielekova, MD; Thomas Howard; Amy N. Packer; Nancy Richert, MD; Gregg Blevins, MD; Joan Ohayon, CRNP; Thomas A. Waldmann, MD; Henry F. McFarland, MD; Roland Martin, MD

Background: Several questions arise concerning the use of the anti-CD25 antibody daclizumab to treat multiple sclerosis (MS).

Objectives: To answer the following 3 questions related to the efficacy of daclizumab therapy in patients with MS: Is the therapeutic effect of daclizumab dependent on combination with interferon beta? Is a higher dosage of daclizumab more efficacious in patients with persistent disease activity? Can biomarkers predict full vs partial therapeutic response to daclizumab?

Design: An open-label baseline vs treatment phase II clinical trial of daclizumab in patients having MS with inadequate response to interferon beta. Three months of interferon beta treatment at baseline were followed by 5.5 months of interferon beta–daclizumab combination therapy. If patients experienced more than 75% reduction of contrast-enhancing lesions (CELs) on brain magnetic resonance imaging at month 5.5 compared with baseline, daclizumab was continued as monotherapy for 10 months. Otherwise, the dosage of daclizumab was doubled.

Setting: Neuroimmunology Branch, National Institute of Neurological Disorders and Stroke, Bethesda, Maryland.

Patients: Fifteen patients with MS receiving standard preparations of interferon beta who experienced more than 1 MS exacerbation or whose clinical disability increased in the preceding 12 months and who had at least 2 CELs on baseline brain magnetic resonance images.

Intervention: Daclizumab (1 mg/kg) as an intravenous infusion every 4 weeks in combination with interferon beta (months 0-5.5) and as monotherapy (months 6.5-15.5).

Main Outcome Measures: The primary outcome was the reduction of CELs among interferon beta monotherapy, interferon beta–daclizumab combination therapy, and daclizumab monotherapy. The secondary outcomes included immunologic biomarkers and changes in clinical disability.

Results: Overall, 5 of 15 patients (33%) experienced adverse effects of therapy. Two patients developed systemic adverse effects, and daclizumab therapy was discontinued. Although daclizumab monotherapy was efficacious in 9 of 13 patients with MS, interferon beta–daclizumab combination therapy was necessary to stabilize disease activity in the other 4 patients. Daclizumab therapy led to 72% inhibition of new CELs and significant improvement in clinical disability. Pilot biomarkers (increase in CD56bright natural killer cells and decrease in CD8 T cells) were identified that can differentiate between full and partial daclizumab responders.

Conclusions: Daclizumab monotherapy is effective in most patients who experienced persistent MS disease activity with interferon beta therapy. Interferon beta–daclizumab combination therapy or higher dosages of daclizumab may be necessary to achieve optimal therapeutic response in all patients. Biomarkers may identify patients with suboptimal response to daclizumab monotherapy. Administration among a large patient sample during a longer period is needed to fully define the safety and long-term efficacy of daclizumab as treatment for high-inflammatory MS.

Trial Registration: clinicaltrials.gov Identifier: NCT00001934


MULTIPLE SCLEROSIS (MS) is an immune-mediated disorder of the brain and spinal cord in which at least part of the inflammatory process can be objectively measured by contrast-enhancing lesions (CELs) on brain magnetic resonance (MR) imaging. When used as an add-on therapy to interferon beta, daclizumab significantly inhibits CELs in MS. Studies from our laboratory revealed an unexpected mechanism of action of daclizumab in MS—it increases the quantity and function of immunoregulatory CD56bright natural killer (NK) cells, which

Author Affiliations are listed at the end of this article.
downregulate adaptive T-cell responses. Although overall NK cell quantity or function has been described as diminished in patients with MS, the quantity of immunoregulatory CD56\textsuperscript{bright} NK cells has not been systematically studied. Studies from our laboratory first identified expansion of these cells by daclizumab based on their combined phenotype as CD8\textsuperscript{dim} lymphocytes that are CD3\textsuperscript{+}, CD4\textsuperscript{+}, and CD19\textsuperscript{−}. Recently, an unbiased large-scale immunophenotyping approach identified a diminished quantity of CD8\textsuperscript{dim} cells as a biomarker that distinguishes patients with MS and patients with clinically isolated syndrome from healthy control subjects. Furthermore, numbers of CD56\textsuperscript{bright} NK cells are increased by several other effective immunomodulatory therapies in MS such as interferon beta\textsuperscript{−} and rituximab. These data suggest that CD56\textsuperscript{bright} NK cells may be relevant immunoregulatory cells in MS. Because type 1 interferons are known to enhance NK cell function\textsuperscript{3} and, conversely, because NK cells induce interferon beta during viral infection,\textsuperscript{10} the following important question emerged: Is synergism between interferon beta and daclizumab required for therapeutic efficacy in MS? In addition, although intravenous daclizumab (1 mg/kg) administered every 4 weeks blocks more than 95% of CD25 on T cells in the blood,\textsuperscript{4} it is unclear whether CD25 saturation is also achieved in tissues and whether a higher dosage of daclizumab may be more efficacious. This article reports the MR imaging and clinical and immunologic results of a second open-label baseline vs treatment phase II clinical trial of daclizumab in patients with MS that was performed at the Neuroimmunology Branch, National Institute of Neurological Disorders and Stroke, National Institutes of Health, Bethesda, Maryland, and that addresses these new and important questions. In addition, the article describes pilot biomarkers that potentially allow the early identification of patients who may not respond optimally to daclizumab monotherapy at the standard dosage. Instead, these patients may need a higher dosage of daclizumab or combination with interferon beta to achieve full therapeutic benefit.

**METHODS**

The trial design is shown in Figure 1. The trial was approved by the institutional review board. The inclusion criteria were as follows: age 18 to 65 years, relapsing-remitting or secondary progressive MS, Expanded Disability Status Scale (EDSS\textsuperscript{11}) score of 1.0 to 6.3, and suboptimal response to interferon beta (defined as ≥1 MS exacerbation or progression of sustained clinical disability by ≥1 EDSS step in the preceding 12 months). The presence of neutralizing antibodies to interferon beta was not assessed and did not represent an exclusion criterion. Patients with concurrent medical conditions that could affect the immune system or progression of disability were excluded from the study. Multiple sclerosis exacerbations were defined based on criteria by Schumacher et al\textsuperscript{12} and were treated with intravenous methylprednisolone sodium succinate (1 g/d for 5 days). Magnetic resonance images obtained within 28 days of intravenous administration of methylprednisolone were disregarded and were substituted by MR images from the following month. Four of 15 enrolled patients participated in a previously published short-term National Institutes of Health clinical trial of daclizumab plus interferon beta.\textsuperscript{1}

**STUDY TREATMENT**

To be enrolled, patients had to have at least 0.67 new CELs per month on baseline MR images (Figure 1). Daclizumab (1 mg/kg) was administered as an intravenous infusion, initially 2 weeks apart for the first 2 doses and then every 4 weeks. After 7 doses of daclizumab (at month 5.5), the total number of CELs on a single MR image series was compared with the mean number of CELs during baseline. If more than 75% reduction of CELs was observed, interferon beta therapy was slowly withdrawn (during 2-4 weeks). If 75% or less reduction of CELs was observed at month 5.5, interferon beta therapy was continued, and the daclizumab dosage was increased to 2 mg/kg every 4 weeks. The quantity of CELs was analyzed monthly. If a sustained (≥2-month) increase in CELs was noted with daclizumab monotherapy (above the mean with combination therapy), interferon beta therapy was re instituted, and the patient continued receiving interferon beta–daclizumab combination therapy until the end of the trial.

![Figure 1](http://archneur.jamanetwork.com/pdfaccess.ashx?url=/data/journals/neur/7754/)
To identify biomarkers that could predict full therapeutic response to daclizumab after withdrawal of interferon beta therapy, we defined partial responders to daclizumab monotherapy. These were patients who either required interferon beta–daclizumab combination therapy or experienced MS exacerbation, or those who had 50% or less reduction of CELs with daclizumab therapy.

OUTCOMES MEASURES

The primary outcome measure was the reduction of new and total CELs from the baseline treatment period (interferon beta therapy), to the interferon beta–daclizumab combination therapy, and to the daclizumab monotherapy period. The secondary outcomes included the following: change in the volume of CELs, volume of T2-weighted lesions, volume of T1-weighted lesion hypointensities, brain atrophy (brain fractional volume), and change in clinical measures of disability. The change in clinical measures of disability was assessed by the following scores: EDSS11 (0 [normal] to 10 [death from MS]), Scripps Neurological Rating Scale13 (100 [normal] to 0 [death from MS]), and Multiple Sclerosis Functional Composite14 (MSFC [calculated as a z-score based on all collective baseline data in the cohort; higher numbers indicate improvement of disability]).

IMMUNOLOGIC BIOMARKERS

Whole-blood samples were collected every 2 to 3 months and were processed within 1 hour of collection. Red blood cells were lysed by osmotic pressure, and white blood cells were stained using a panel of commercially available antibodies and analyzed by flow cytometry as previously described.1 Percentages of CD4+/CD3+ and CD8+/CD3+ T cells and CD56bright/CD3+ and CD56dim/CD3− NK cells were calculated for each time point. Absolute numbers of these cellular subpopulations were derived from the absolute lymphocyte count provided by the National Institutes of Health clinical center laboratory from identical sample collections.

MR IMAGING ANALYSIS

Magnetic resonance images were acquired at 1.5 T using a standard protocol.1 CELs were recorded on hard-copy films by consensus of 2 radiologists. All volumetric analyses were performed by a single experienced rater (T.H.) using semi-automated thresholding techniques (PV-WAVE13 and MEDx) as previously described.1

STATISTICAL ANALYSIS

Statistical differences between treatment periods were based on Friedman repeated-measures analysis of variance on ranks with predetermined P < .05, using the Newman-Keuls test to correct for multiple comparisons. Differences between full and partial responders were based on the Mann-Whitney rank sum test.

RESULTS

DEMOGRAPHICS AND SAFETY

The patient population is summarized in the Table. Two patients did not complete the trial because of adverse effects possibly related to daclizumab monotherapy. Both patients (patient 5 and patient 13) developed systemic immune responses 1 to 2 months after withdrawal of interferon beta therapy, characterized by mouth ulcers, photosensitivity rash, and transient formation of autoantibodies that required corticosteroid therapy for resolution. Two other patients developed adverse events that required transient cessation of daclizumab therapy because of lymphopenia (patient 6) and generalized lymphadenopathy (patient 7). Both patients received all subsequent courses of treatment with excellent outcomes. Patient 1 had a transient increase in bilirubin levels that did not necessitate discontinuation of daclizumab therapy.

EFFICACY

Patient 11 did not reach the interim end point of CEL reduction by more than 75% at month 5.5 and was given a double dose of daclizumab in addition to continuation of interferon beta therapy, with a subsequent excellent therapeutic response. In 14 patients, interferon beta was withdrawn after 5.5 months, but in 3 patients it was restarted because of sustained reappearance of CELs. Trial results (intent-to-treat analysis among all 15 patients) are shown in Figure 2. We observed 72% inhibition of new CELs (P = .002) and 77% inhibition of total CELs (P < .001) with daclizumab therapy. This inhibition of CELs developed gradually and continued during dosing so that the reduction in the volume of CELs reached statistical significance (P < .001) even when comparing combination therapy and monotherapy periods (Figure 2A). We observed improvements in all clinical measures of disability (P < .001 for the EDSS and Scripps Neurological Rating Scale and P = .002 for the MSFC) (Figure 2B). There were no significant changes in the volume of T2-weighted lesions (P = .42), while the volume of T1-weighted lesion hypointensities (P = .02) and the brain fractional volume (P = .009) increased transiently between baseline and combination therapy but stabilized between combination therapy and monotherapy (Figure 2C). The average/median whole-brain magnetization transfer ratio did not change significantly (P = .56) from baseline (0.334/0.340) to combination therapy (0.335/0.337) or monotherapy (0.336/0.339).

IMMUNOLOGIC STUDIES

It was previously reported that daclizumab therapy increases the number of CD56bright NK cells and that this increase in numbers correlates with the decrease in absolute numbers of peripheral CD4+ and CD8+ T cells.4 Results of this trial allowed us to answer the question whether this effect is related to interferon beta therapy. We observed a further increase in the number of CD56bright NK cells (P < .001) and a concomitant decrease in the absolute numbers of CD4+ (P = .008) and CD8+ (P = .002) T cells with daclizumab monotherapy compared with interferon beta–daclizumab combination therapy (Figure 3A). Based on the previous observation that CD56bright NK cells regulate T-cell responses,5 we assessed the ratios between CD56bright NK cells and effector lymphocyte subsets (Figure 3B), which also further decreased during daclizumab monotherapy (P < .001 for CD4+/CD56bright NK and CD8+/CD56bright NK cell ratios).

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Seven patients fulfilled criteria for partial responders to daclizumab monotherapy (see the “Methods” section and the Table). When analyzing immunologic differences between full and partial responders, full responders had at least a 10% decrease in CD8⁺ T cells and CD4⁺ T cells and at least a 300% increase in the number of CD56bright NK cells during combination therapy compared with baseline (Figure 3C). Partial responders showed an increase or less than a 10% decrease in CD4⁺ T cells and CD8⁺ T cells and less than a 300% increase in the number of CD56 bright NK cells. Although full responders further increased the percentage of CD56bright NK cells (and CD8αbright/CD3⁺ lymphocytes) during daclizumab monotherapy to more than 400% of baseline, partial responders experienced a significantly smaller increase in these regulatory cells (Figure 3C, last panel).

Our data demonstrate that while daclizumab monotherapy is effective for most patients with MS having persistent MR imaging and clinical evidence of disease activity while receiving interferon beta therapy, there is an additive effect of interferon beta–daclizumab combination therapy that may be advantageous for patients whose MS is most difficult to treat. Compared with a previous study by Rose et al that was performed concurrently with the initial daclizumab study at the Neuroimmunology Branch, the present study provides important additional information. First, in addition to EDSS and Scripps Neurological Rating Scale clinical scores, which should be inter-
interpreted with caution in an open-label trial because of their high rater dependency, we provide data on the MSFC, which is based on objectively quantifiable measures. Hence, the continuous improvement on the MSFC between combination therapy and monotherapy is encouraging. Although a learning effect may influence MSFC scores when tested infrequently, all 3 components of the MSFC were tested monthly in our trial, making it unlikely that learning could have affected the results after more than 10 months of testing.

Second, in addition to CEL analysis, our study evaluates volumetric MR imaging measures, including magnetization transfer ratios. Although the improvement in disability measures suggests the possibility that daclizumab therapy enhances repair, we consider this unlikely in view of its apparent lack of effect on the volume of T1-weighted lesion hypointensities and the brain fractional volume. Nevertheless, these MR imaging measures may detect edema associated with inflammation, which makes them less sensitive markers for tissue destruction in short-term clinical trials of MS.\textsuperscript{16} However, neither did we observe any improvement in whole-brain magnetization transfer ratios, even though this too may be a measure that is insensitive to depict focal lesion-related repair.

Third, our immunologic data demonstrated further increases in CD56\textsuperscript{bright} NK cells and additional decreases in the number of CD4\textsuperscript{+} and CD8\textsuperscript{+} T cells after cessation of interferon beta therapy. This indicates that interferon beta and daclizumab have distinct immunologic mechanisms of action; therefore, their combination is more effective than either drug alone.

Fourth, although we treated only 1 patient with a higher dosage of daclizumab (2 mg/kg), the remarkable efficacy of this dosage (complete elimination of CELs in this patient for 10 months) suggests that higher dosages of daclizumab deserve further study as an alternative to interferon beta–daclizumab combination therapy. Our observation of greater than 95% saturation of CD25 with daclizumab on peripheral blood lymphocytes in all patients, irrespective of their response status (data not shown), led us to believe that higher dosages of daclizumab may be necessary to fully saturate CD25 in tissues.

Fifth, it would be of great benefit to have biomarkers that allow prediction of treatment response. The results of our study indicate that the extent of changes in CD8\textsuperscript{+} T-cell and CD56\textsuperscript{bright} NK cell counts induced by daclizumab within the first 2 to 4 months of therapy may identify patients who are unlikely to have a full therapeutic response on withdrawal of interferon beta therapy. These biomarker findings must be considered preliminary but deserve validation in large phase II or III trials of daclizumab.

Therapeutic efficacy of daclizumab in inhibiting brain inflammation in MS has been confirmed by several trials, including a recently reported randomized double-blind phase II trial of interferon beta–daclizumab combination therapy (CHOICE [Daclizumab in Patients With Active Relapsing-Remitting Multiple Sclerosis on Concurrent Interferon-Beta Therapy] study).\textsuperscript{17} This trial examined

\begin{figure}
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\caption{Clinical and magnetic resonance (MR) imaging trial results. A, Effect of daclizumab therapy on primary outcome measures, including the numbers of new and total contrast-enhancing lesions (CELS) and the volume of CELs. B, Effect of daclizumab therapy on secondary (clinical) outcome measures, including scores on the Expanded Disability Status Scale (EDSS), Scripps Neurological Rating Scale (NRS), and Multiple Sclerosis Functional Composite (MSFC). C, Effect of daclizumab therapy on secondary (MR imaging) outcome measures, including volume of T2-weighted lesions (T2L volume), volume of T1-weighted lesions (T1L volume), and brain atrophy (brain fractional volume [BFV]). For each patient, the means of the treatment periods are shown. The medians of the whole cohort are bolded. \textit{Statistically significant differences (P < .05) between time points. Comb Th indicates combination therapy; Mono Th, monotherapy; and ns, not significant.}}
\end{figure}
Figure 3. Immunologic results. A, Changes in the subpopulations of CD56bright natural killer (NK) cells and CD8+ and CD4+ T cells during daclizumab (Dacliz) therapy. The medians of the whole cohort are bolded. Statistically significant differences (P < .05) between baseline, combination therapy, and monotherapy time points are indicated by horizontal bidirectional arrows (↔) in the graphs. B, The ratios of CD8+ and CD4+ T cells and CD56bright NK cells (responding populations) and CD56bright NK cells (regulatory population). Each patient point represents the mean of several treatment period time points (Figure 1). Statistically significant differences (P < .05) are indicated by an asterisk. C, Differences in immunologic markers between 8 full responders (FR) and 7 partial responders (PR) to daclizumab monotherapy (Table). Individualized percentage changes in biomarkers compared with baseline were calculated for all patients and are depicted as box plots. Black horizontal line represents median; white horizontal line, group mean; blue dashed line, baseline (100%) values. Comb Th indicates combination therapy; Mono Th, monotherapy.
the efficacy of a formulation for subcutaneous delivery of 2 dosages of daclizumab (1 mg/kg and 2 mg/kg) administered every 2 weeks vs placebo. The study patients who received the higher dosage had a statistically significant 72% reduction in the number of new or enlarged CELs at week 24 compared with patients receiving interferon beta therapy alone. Other phase II trials, including those testing the efficacy of daclizumab monotherapy, are ongoing.17 However, daclizumab must undergo rigorous testing in phase III double-blind clinical trials before it can be considered a safe and effective therapy for patients with MS.

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Author Affiliations: Neuroimmunology Branch, National Institute of Neurological Disorders and Stroke (Drs Bielekova, Richert, Blevins, and McFarland and Mr Howard and Ms Packer and Ohayon), and Metabolism Branch, National Cancer Institute (Dr Waldmann), National Institutes of Health, Bethesda, Maryland; Division of Neurology, University of Alberta, Edmonton, Alberta, Canada (Dr Blevins); and Institute of Neuroimmunology and Clinical Multiple Sclerosis Research, Center for Molecular Neurobiology Hamburg, University Clinic Eppendorf, Hamburg, Germany (Dr Martin).

Correspondence: Bibiana Bielekova, MD, Neuroimmunology Branch, National Institute of Neurological Disorders and Stroke, National Institutes of Health, Bldg 10, Room 5C103, 10 Center Dr, MSC 1400, Bethesda, MD 20892 (Bibi.Bielekova@nih.gov).

Author Contributions: Study concept and design: Bielekova, Waldmann, McFarland, and Martin. Acquisition of data: Bielekova, Howard, Packer, Richert, Blevins, and Ohayon. Analysis and interpretation of data: Bielekova, Howard, Packer, and Richert. Drafting of the manuscript: Bielekova and Richert. Critical revision of the manuscript for important intellectual content: Bielekova, Howard, Richert, Blevins, Ohayon, Waldmann, McFarland, and Martin. Statistical analysis: Bielekova. Obtained funding: McFarland and Martin. Administrative, technical, and material support: Bielekova, Howard, Waldmann, and McFarland. Study supervision: Bielekova, Richert, McFarland, and Martin.

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REFERENCES


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