Monoclonal antibody targeting BDCA2 ameliorates skin lesions in systemic lupus erythematosus

Richard Furie, …, Dania Rabah, Nathalie Franchimont


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TITLE: "Monoclonal Antibody Targeting BDCA2 Ameliorates Skin Lesions in Systemic Lupus Erythematosus"

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ABSTRACT (250 words/250 max word count)

Background/Purpose: Plasmacytoid dendritic cells (pDC) produce large amounts of type I IFN (IFN-I), cytokines convincingly linked to systemic lupus erythematosus (SLE) pathogenesis. BIIB059 is a humanized mAb that binds BDCA2, a pDC-specific receptor that inhibits the production of IFN-I and other inflammatory mediators when ligated. A first-in-human study was conducted to assess safety, tolerability, pharmacokinetic (PK) and pharmacodynamic (PD) effects of single BIIB059 doses in healthy volunteers (HV) and patients with SLE with active cutaneous disease as well as proof of biological activity and preliminary clinical response in the SLE cohort.

Methods: A randomized, double-blind, placebo-controlled, clinical trial was conducted in HV (n=54) and patients with SLE (n=12). All subjects were monitored for adverse events. Serum BIIB059 concentrations, BDCA2 levels on pDCs, and IFN-responsive biomarkers in whole blood and skin biopsies were measured. Skin disease activity was determined using the Cutaneous Lupus Erythematosus Disease Area and Severity Index Activity (CLASI-A).

Results: Single doses of BIIB059 were associated with favorable safety and PK profiles. BIIB059 administration led to BDCA2 internalization on pDCs, which correlated with circulating BIIB059 levels. BIIB059 administration in patients with SLE decreased expression of IFN response genes in blood, normalized MxA expression and reduced immune infiltrates in skin lesions, and decreased CLASI-A score.
Conclusion: Single doses of BIIB059 were associated with favorable safety and PK/PD profiles, and robust target engagement and biological activity, supporting further development of BIIB059 in SLE. The data suggest that targeting pDCs may be beneficial for patients with SLE, especially those with cutaneous manifestations.

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Specialty: Immunology

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INTRODUCTION

Systemic lupus erythematosus (SLE) is a chronic autoimmune disease characterized by autoantibody production, inflammation, and tissue damage in multiple organs resulting from the activation of numerous proinflammatory pathways (1, 2). Clinical manifestations vary widely among patients and commonly include rash, arthritis, and nephritis, but the central nervous system and other major organ systems can also be affected (3).

Therapies used to treat SLE, such as antimalarials, corticosteroids, and immunosuppressive drugs, are only partially effective and have a wide range of toxicities (4–7). Thus, there is an unmet need for more efficacious and safer therapies that specifically target critical pathways in SLE. Type I IFN (IFN-I) play a major role in the pathogenesis of SLE (8, 9), and several approaches for targeting the IFN-I pathway have been explored in clinical trials. These include neutralizing mAbs against subtypes of IFN-I (10). Positive results from phase II SLE clinical trials with anti-IFNα mAb (sifalimumab) and anti-IFNαβ receptor (anifrolumab) support the pathogenic role of the IFN-I pathway in SLE (11, 12).

Plasmacytoid dendritic cells (pDCs) are a specialized population of bone marrow–derived cells that synthesize large amounts of IFN-I in response to ligands that engage endosomal Toll-like receptor (TLR)7 or TLR9 (13). pDCs are also thought to be the major producers of IFN-I in response to immune complexes (13, 14). In SLE, pDC numbers decrease in the blood and accumulate in affected organs, such as lesional skin or kidneys (15–23). The accumulation of pDCs in skin lesions or kidneys, together with their ability to produce copious amounts of IFN-I,
make pDCs an appealing target for therapeutic intervention in SLE. Depletion of pDCs has been shown to be beneficial in preclinical mouse models of TLR7/TLR9-dependent cutaneous diseases as well as in lupus nephritis, which further supports the pathogenic potential of pDCs (24–27).

BIIB059 is a humanized IgG1 mAb that specifically recognizes blood dendritic cell antigen 2 (BDCA2), which is uniquely expressed on the surface of human pDCs (28, 29). BIIB059 binding to BDCA2 results in its rapid internalization from the cell surface of human pDCs, and the subsequent inhibition of IFN-I (all subtypes), cytokine, and chemokine production by pDCs (28, 30–34). In this first-in-human phase 1 study (NCT02106897), the safety, tolerability, and pharmacokinetics (PK) of single doses of BIIB059 were assessed in both healthy volunteers (HV) and a cohort of patients with SLE and active skin disease. Effects on pharmacodynamic markers and clinical activity were evaluated.
RESULTS

Safety, tolerability, and immunogenicity after administration of BIIB059 in healthy volunteers and patients with SLE.

First-in-human evaluation of BIIB059 was conducted in a 3-part phase 1 study (NCT02106897): single ascending doses in HV (part 1), a single dose in patients with SLE (part 2), and multiple ascending doses in HV and patients with SLE (part 3) (Supplemental Figure 1). This study reports the safety, tolerability, pharmacokinetics (PK), pharmacodynamics (PD), immunogenicity, and proof of biological activity following a single administration of BIIB059 in HV and patients with SLE (parts 1 and 2, respectively). Part 1 was dose ascending and consisted of 6 cohorts of HV receiving a single intravenous (i.v.) infusion of BIIB059 with doses ranging from 0.05 mg/kg to 20 mg/kg (Figure 1 and Supplemental Table 1). An additional cohort of HV (cohort 7) was enrolled to receive a single fixed subcutaneous (s.c.) dose of 50 mg BIIB059 to determine the relative bioavailability of s.c. compared with i.v. administration (Figure 1 and Supplemental Table 1). In part 2 of the study, a single i.v. dose of BIIB059 (20 mg/kg) was evaluated in adult patients with SLE and active cutaneous lupus erythematosus (CLE) as defined by the presence of acute, subacute, and/or chronic cutaneous lupus at the time of screening and randomization (cohort 8). The dose level in cohort 8 was selected to match the highest evaluated and tolerable dose from part 1 (Figure 1 and Supplemental Table 1). In parts 1 and 2, the demographic and baseline characteristics were similar between the pooled placebo group and the pooled BIIB059 group, and all patients with SLE enrolled had mild to moderate disease activity and active skin manifestations as measured by the Systemic Lupus Erythematosus Disease Activity Index 2000
(SLEDAI-2K) 35), Cutaneous Lupus Erythematosus Disease Area and Severity Index Activity (CLASI-A) scoring (36-37) (Tables 1, 2 and Supplemental results).

In part 1, single-dose administration of BIIB059 was well tolerated across all dose levels and treatment groups. Most of the adverse events (AEs) were mild to moderate in severity, and there were no serious AEs (SAEs). The most commonly reported AE was upper respiratory tract infection in 3 HV treated with BIIB059 (Supplemental Table 2). One event of headache was considered related to BIIB059 in the 1 mg/kg group. In part 2, single-dose administration of BIIB059 in patients with SLE was well tolerated (Table 3). One patient experienced a total of 9 SAEs, the first starting on day 77 and the last occurring on day 150, after a single treatment with BIIB059 20 mg/kg i.v. All SAEs were thought to be unrelated to BIIB059 by the investigator (Supplemental results). Most of the AEs were mild to moderate in severity (Table 3), and the most commonly reported AE was upper respiratory tract infection in 3 patients treated with BIIB059 (supplemental Table 2). One treated patient developed Herpes zoster on day 141, which was considered related to the study drug by the investigator and moderate in severity in the 20 mg/kg group.

Sporadic out-of-range values were noted for hematology and blood chemistry parameters; however, no clinically significant differences between the treatments were observed. There were no relevant findings observed for vaccine titer data, immunoglobulin levels, complement levels, immunophenotyping, white blood cell counts (WBC) and absolute differential counts in any part of the study (Supplemental Figure 4 and data not shown). There were no clinically
significant changes in physical examinations or ECG, and no dose-dependent patterns of abnormalities were observed. None of the study participants discontinued the study treatment owing to AEs in either part 1 or part 2.

Overall, 6 of 38 HV and no patients with SLE receiving BIIB059 tested positive for anti-BIIB059 binding Ab. Of these, 4 were transient responses and 2 were persistent, low-titer responses (data not shown). These antidrug Ab did not affect BIIB059 exposure (PK) or PD and there was no association with safety events.

**Pharmacokinetic and pharmacodynamic analyses in HV and patients with SLE.**

Following a single 1-hour i.v. infusion of BIIB059 (0.05–20 mg/kg) in HV, serum BIIB059 C\text{max} and total AUC from time 0 extrapolated to infinity (AUC\text{∞}) increased with dose (Figure 2A and Table 4). The deviation from dose proportionality at low dose levels was driven by target-mediated clearance of BIIB059 (<1mg/kg). Serum BIIB059 declined multi-exponentially with mean t\text{1/2} values generally increasing with dose, ranging from approximately 3.5 days (0.05 mg/kg) to 27 days (10 mg/kg and 20 mg/kg) (Table 4). Following single s.c. administrations of 50 mg BIIB059 to HV, BIIB059 was slowly absorbed with a t\text{max} of approximately 6 days and a mean terminal t\text{1/2} of 12 days. In patients with SLE, a single i.v. infusion of 20 mg/kg BIIB059 achieved maximum serum concentration at a median t\text{max} of approximately 2 hours and was eliminated with a mean terminal t\text{1/2} of 18 days. BIIB059 exposure (AUC) was approximately 40% lower in patients with SLE compared with HV at the same dose (Figure 2B and Table 4).
BIIB059 exposure leads to rapid internalization of BDCA2 on human pDCs *in vitro* and in cynomolgus pDCs *in vivo* (28). In this clinical study, BDCA2 internalization on pDCs was evaluated both as a measure of target engagement and PD response using a flow cytometric assay. Specifically, the assay incorporates a non–cross-blocking antibody that recognizes an epitope of BDCA2 that is different from that of BIIB059. Reductions in BDCA2 levels on pDCs compared with baseline were observed in all BIIB059-treated patients but not following placebo administration. More than 90% of surface BDCA2 on pDCs was internalized in HV and SLE subjects within 1 hour to 2 days post-BIIB059 administration (Figure 3 A and B). The duration of BDCA2 internalization was dose dependent, with BDCA2 on the surface of pDCs returning to baseline levels within a shorter period of time at lower doses compared with higher doses (Figure 3A). On average, the duration of BDCA2 internalization after a single injection of BIIB059 was 14 days at the lowest dose (0.05 mg/kg) in HV, whereas at the highest dose (20 mg/kg), BDCA2 continued to be internalized in most subjects at the last time point tested (112 days) in HV (Figure 3, A). Comparisons of individual exposure data and BDCA2 levels on pDC cell surfaces for all treated subjects indicated that circulating BIIB059 must drop below a threshold of approximately 1 μg/mL before BDCA2 on pDC cell surfaces starts returning to baseline levels (data not shown). Since the BIIB059 exposure (AUC) was lower in patients with SLE compared to HV, BIIB059 serum concentration dropped below the 1 μg/mL threshold on days 84 and 112 in some patients, and therefore BDCA2 levels on pDCs started recovering at these time points (Figure 3B).
Internalization of BDCA2 correlated with circulating levels of BIIB059 in both HV (Figure 3C) and patients with SLE (Figure 3D), establishing a pharmacokinetic/pharmacodynamic (PK/PD) relationship in vivo.

Reduction from baseline in the number of circulating pDCs was observed following BIIB059 administration, even at the lowest dose level tested (Supplemental Figure 2). The observed reduction was transient, with approximately 50% recovery in average pDC numbers by week 2 in BIIB059-treated HV and patients with SLE (Supplemental Figure 2 B-F). In the 20 mg/Kg treatment groups (HV and SLE) recovery in pDC numbers was observed in the presence of > 100 μg/mL of BIIB059 at week 2, when BDCA2 is still fully internalized on pDCs (Supplemental Figure 2G). These data suggest that BIIB059 administration leads to BDCA2 internalization without a sustained decrease in pDC numbers.

**IFN response markers in whole blood and lesional skin.**

Since BIIB059-mediated BDCA2 internalization is functionally linked to inhibition of IFN-I production by pDCs, we assessed whether BIIB059 modulated the activation of the IFN pathway in patients with SLE. To this end, we investigated the expression of IFN response genes (IRG) from whole blood (Supplemental Figure 3) and hallmark IFN response proteins in lesional skin.

IRG were initially selected on the basis of previously published IRG data. These genes were further refined on the basis of the separation between HV and SLE subjects, the correlations among each other, and guidance from an internal SLE cohort (Supplemental Figure 3). Their
expression was measured in whole blood at baseline and several time points post-dose using quantitative PCR. All enrolled patients with SLE showed elevated expression in IRG compared with HV at baseline (Supplemental Figure 3). Single doses of BIIB059 at 20 mg/kg i.v. led to rapid, partial neutralization (~50%) of IRG expression within 24 hours post-dose (Figure 4B) compared with placebo (Figure 4A). Since BIIB059 treatment didn’t impact the immune cell composition in whole blood of treated patients as measured by differential cell count (Supplemental Figure 4), changes in IRG likely reflect the specific effect of BIIB059 on pDCs. Thus, these data contribute to proof of biology as they confirm that pDC-derived IFN-I contribute to the IFN signature detected in the blood of patients with SLE.

PCDs have been shown to accumulate in the skin of patients with SLE, and play an important role in disease pathogenesis (15, 16, 19, 21–23). Therefore, we sought to determine the impact of BIIB059 on the IFN-I response in active skin lesions within the SLE cohort. Skin biopsies from active lesions in 11 of 12 patients were evaluated at baseline (day -1) and week 4 for IFN-regulated proteins MxA (Figure 5, A and B) and IFITM3 (Supplemental Figure 5A) using immunohistochemistry on formalin-fixed 4–5mm punch biopsies.

Marked reductions in MxA % area immunoreactivity were detected in 6 of 7 patients with SLE 4 weeks after BIIB059 administration, with an average week 4 change from baseline of -70% for the BIIB059 cohort (Figure 5B). Although 2 of 4 patients from the placebo group exhibited a decrease in MxA % area compared with baseline, the mean week 4 change from baseline was +12% for the placebo group (Figure 5A). Together, these data indicate that targeting BDCA2 on
pDCs with BIIB059 leads to a robust and sustained inhibition of the IFN pathway in a frequently involved organ (skin) in SLE, and results additionally in partial neutralization of the IFN signature in the blood.

**Correlation of cutaneous IFN response markers and CLASI-A score.**

In addition to assessing the impact of BIIB059 on the activation of the IFN pathway in blood and lesional skin, the activity of cutaneous disease was also determined using CLASI-A score at various time points post- single administration of BIIB059 (Figure 5). Patients were considered responders if they exhibited a CLASI-A score reduction from baseline (day -1) of at least 4 points at week 4 and/or week 12 post-BIIB059 treatment, which is consistent with the defined minimal clinically important difference of CLASI-A (36-37). Skin lesion adjudications were conducted to confirm both a lupus skin diagnosis as well as activity at baseline.

Six of 8 patients with SLE receiving a single dose of 20 mg/kg i.v. BIIB059 were considered responders on the basis of the CLASI-A reduction criteria (Figure 5B). Importantly, the patients who were CLASI-A responders also exhibited significant reductions in lesional skin MxA expression (Figure 5B). Improvement in CLASI-A correlated ($\rho = 0.67$) with reduction in MxA (Figure 5C), suggesting that the activity of the IFN pathway in the skin associates with clinical cutaneous disease activity. These data indicate that a reduction in MxA expression in lesional skin may serve as a robust surrogate biomarker for clinical efficacy.
The reduction in CLASI-A scores observed at week 4 were maintained at week 12 post-BIIB059 treatment in 5 of 6 patients with SLE (Figure 5D). By contrast, 3 of 4 patients who received placebo failed to improve at both weeks 4 and 12 (Figure 5, A and D). The precipitous decline in the CLASI score of placebo patient 1 measured at week 12 (Figure 5D) occurred post-treatment with parenteral methylprednisolone sodium succinate for hand pain administered at day 43 and prednisone treatment for arthritis on days 53–55. These data suggest that administration of a single dose of BIIB059 can lead to a sustained clinical benefit, at least up to 12 weeks.

**Cutaneous MxA expression and histology.**

Given the decrease of the IFN response marker MxA in the lesional skin of patients with SLE after BIIB059 administration, we sought to determine the degree of normalization of skin biomarkers in BIIB059-treated patients compared with HV. To this end, skin biopsies were collected from 8 HV, and the percentage of MxA-positive staining area in the epidermis was measured to establish the normal range (Figure 6). Six of 7 patients in the BIIB059 treatment cohort displayed elevated baseline (day -1) MxA expression above the normal range as determined in this population of 8 HV (Figure 6B). At week 4, BIIB059 treatment reduced MxA expression to the normal range in all but 1 patient (#12). This patient also demonstrated no CLASI-A improvement (Figure 5, B and D). Three of 4 subjects in the placebo group had elevated baseline MxA expression in the skin comparable with the BIIB059 cohort, and did not show any normalization at week 4 (Figure 6B).
Given the clinical and IFN biomarker responses observed in the BIIB059-treated group, we investigated the effects of BIIB059 treatment on the inflammatory cell infiltrates of lesional skin. Skin biopsies were immunoreacted with antiCD45, a pan-leukocyte marker, to detect immune cell infiltration. Cellular infiltrates were detected in most of the lesional skin biopsies of patients with SLE compared with healthy donors (Figure 6D). All CLASI-A responders with elevated baseline papillary dermal CD45+ immunoreactive area in the skin lesions (4 of 5 patients) showed marked reductions in cellular infiltration upon treatment with BIIB059 (Figure 6D). By contrast, CD45+ immunoreactive area remained high in the placebo cohort.

All the skin biomarkers assessed, namely IFN-regulated proteins MxA (Figures 5 and 6) and IFITM3 (Supplemental Figure 5B), CD45+ cellular infiltrates (Figure 6), and pDC (CD123+ cells) (Supplemental Figure 5D) generally demonstrated similar trends in response to BIIB059 treatment. Together, these data indicate that in some patients BIIB059 not only affects the IFN response but also reduces inflammation in lesional skin.
DISCUSSION

This first-in-human study assessed the safety, tolerability, and PK/PD profiles of single ascending doses of BIIB059 (0.05–20 mg/kg) in HV and 20 mg/kg in patients with SLE and active skin disease. Single-dose administration of BIIB059 was well tolerated across all dose levels. Most of the AEs were mild to moderate in severity. One patient with SLE experienced SAEs that were not considered related to BIIB059 treatment. The single-dose i.v. PK profile of BIIB059 was characteristic of a mAb, and increases in exposure were observed with increases in dose (0.05–20 mg/kg) in HV. The absolute bioavailability of the single s.c. dose tested was approximately 50%. In patients with SLE, a single i.v. dose of 20 mg/kg resulted in lower exposure than in HV given the same dose. PDCs are known to be reduced in the peripheral blood of patients with SLE but are increased in target organs, such as active lupus skin lesions or kidneys (15, 16, 19, 21–23). Because all patients with SLE recruited to the study presented with active skin disease, the lower serum concentration observed in patients with SLE compared with HV may be due to the binding of BIIB059 on pDCs accumulated in active skin lesions and, potentially, other tissues.

Previous in vitro studies indicated that BIIB059 binding to BDCA2 results in its rapid internalization from the cell surface of human pDCs, co-localization of the BIIB059-BDCA2 complex in the endolysosomal compartment that is known to be critical for TLR7/9 signaling, and inhibition of IFN-I production (28, 30–34). These observations were recapitulated in cynomolgus monkeys, where a single dose of BIIB059 led to BDCA2 internalization and
corresponding functional inhibition of cynomolgus pDCs \textit{in vivo} (28). In this clinical study, the
determination of BDCA2 receptor level on the pDC cell surface was therefore used to inform on
both target engagement and PD response. Consistent with the preclinical findings, BIIB059
treatment led to a rapid and sharp decrease of BDCA2 levels on the surface of pDCs in both HV
and patients with SLE. BDCA2 internalization correlated with circulating BIIB059 levels in
treated study participants, thereby establishing a PK/PD correlation \textit{in vivo}. More specifically,
the dose-dependent return to baseline of BDCA2 levels indicated that a threshold of circulating
BIIB059 must be reached (~1 μg/ml), below which there is insufficient BIIB059 to saturate the
BDCA2 receptors and mediate internalization, resulting in BDCA2 returning to the cell surface.

Previous preclinical studies demonstrated that BIIB059 does not affect pDC numbers in
cynomolgus monkeys (28). Administration of BIIB059 to human subjects resulted in a transient
decrease in circulating pDC numbers at all dose levels in both HV and patients with SLE.
Although the main mechanism of action of BIIB059 is the engagement of the inhibitory receptor
BDCA2 to dampen pDC responses, it is possible that BIIB059 leads to antibody-mediated
depletion of human pDCs owing to its effector competent Fc region. However, this effect is
unlikely to be a robust mechanism of action of BIIB059, as demonstrated by the rather transient
effect on pDC numbers. Additionally, the rapid, sustained, and near-complete internalization of
BIIB059 after binding of BDCA2 would likely preclude any efficient antibody-mediated pDC
depletion \textit{in vivo}. 
In addition to assessing PK, PD, safety, and tolerability, we sought to confirm proof of biological activity of BIIB059 in patients with SLE with active skin disease. On the basis of the mechanism of action of BIIB059, the biological activity should be manifested by the inhibition of pDC-derived IFN-I and consequent dampening of the IFN response in whole blood and skin lesions in patients with SLE. Patients who received BIIB059 demonstrated a reduction of ~50% in IRG expression in whole blood 24 hours after administration confirming that pDCs partially contribute to systemic IFN-I activation. By contrast with the results in blood, BIIB059 treatment was very effective at normalizing IFN response proteins (MxA and IFITM3) in lesional skin. Normalization of MxA expression occurred in 5 of 6 patients with high MxA expression at baseline upon treatment with BIIB059. None of the 4 placebo-treated patients with elevated baseline MxA demonstrated normalization of MxA expression. The effects of BIIB059 on IFN-I activity in the skin of patients with SLE were observed at week 4 after a single administration. Biopsies were collected only at week 4 post-treatment; therefore, based on the sustained improvement in CLASI-A responses in some patients (at least up to week 12), it is possible that the BIIB059-mediated reduction in IFN-I response in the skin is maintained for a longer period.

Our data confirm that pDCs are the major producers of IFN-I in the skin of established CLE lesions (38). PDCs have been reported to account for up to 5–10% of the immune infiltrate in lesional skin of patients with SLE, where interferogenic immune complexes are known to be deposited, and can produce 1000-fold more IFN than other cell types (19, 38, 39). By targeting BDCA2, BIIB059 was effective at inhibiting pDC-derived IFN-I in the skin and normalizing the IFN
response in patients with SLE, thus confirming the biological activity of BIIB059 in vivo in the target organ.

In addition to affecting the IFN response, improvement in skin disease activity was also observed upon treatment with BIIB059. Notably, the same patients that demonstrated reductions in MxA expression were also classified as clinical responders on the basis of a 4-point reduction in CLASI-A score at week 4 and/or week 12 after a single injection of BIIB059. Improvement in CLASI-A scores correlated with the percentage reduction in MxA expression in the skin lesions. Of note, no associations were observed between IRG score change in whole blood and CLASI-A score change in patients with SLE (data not shown). These data suggest that local pDC-derived IFN-I in lesional skin rather than systemic IFN-I may play a key role in CLE pathogenesis. In this context, in vivo administration of BIIB059 appears to inhibit IFN-I production effectively by pDCs in the skin, leading to the clinical cutaneous benefit observed in this phase I study.

We also observed that CLASI-A responders with elevated baseline CD45+ cellular infiltration in their skin lesions exhibited reductions in immune cellular infiltration upon treatment with BIIB059. This finding supports the hypothesis that pDCs are critical for maintaining the inflammatory environment in SLE skin lesions. BIIB059-mediated functional inhibition of pDCs was shown to inhibit all pDC-derived cytokines and chemokines in vitro, including IFNλ1 (type III IFN) (Supplemental Figure 6). Type III IFN, comprised of IFNλ1 (IL-29), IFNλ2 (IL28a), and IFNλ3 (IL-28b), bind to a different receptor than IFN-I but induce a similar signaling cascade and IFN
response, including driving MxA expression (40). Although pDCs are not the major producers of the non–IFN-I inflammatory mediators, accumulation of pDCs in affected skin could make them an appreciable source capable of supporting the recruitment of inflammatory cells into the lesions and amplifying the IFN response (MxA) via IFNλ in addition to IFN-I. Thus, the overall effect of BIIB059 on skin immune infiltration could be mediated by the inhibition of both pDC-derived IFN-I and proinflammatory mediators, including chemokines, and as such BIIB059 may provide a broad therapeutic benefit in SLE (Figure 7).

In this small phase I clinical study, 2 patients treated with BIIB059 were classified as non-responders on the basis of CLASI-A reduction criteria at week 4 and/or week 12. One of the 2 non-responders, for whom a skin biopsy was available, did not display reductions in IFN response or inflammatory infiltration in the skin. This lack of response in skin biomarkers and disease activity could not be explained by inadequate drug exposure. A multiple-dose regimen of BIIB059 and a study with a larger number patients are needed to understand better and confirm the potential clinical benefit of BIIB059 in the skin but also possibly in other target organs affected by lupus. In this small phase 1 study, the number of SLE patients with extra-cutaneous manifestations was extremely low precluding any meaningful conclusions of the effect of BIIB059 on other systemic manifestations of the disease or analyses of the SLEDAI-2K. BIIB059 is currently being evaluated in a phase 2 clinical trial in patients with active SLE and patients with active CLE (NCT02847598).
BIIB059 is the first therapy to specifically target pDCs in patients with SLE. The primary objective of this first-in-human study was achieved by establishing PK/PD correlations in vivo and demonstrating tolerability and a favorable safety profile for BIIB059. We opted for an organ-specific approach by studying the effects of pDC inhibition in the skin of patients with SLE. With the caveat that the SLE cohort had a small number of patients with SLE (12 total) our results highlight the central role of pDC-derived IFN-1 in the pathogenesis of skin manifestations in SLE and suggest that targeting pDCs with BIIB059 is a promising therapy for SLE and CLE.
SUBJECTS, MATERIALS, AND METHODS

Study design.

This study (study code 230LE101) was a randomized, multicenter, phase I b, placebo-controlled, single ascending dose and multiple ascending dose trial of BIIB059 in HV (parts 1 and 3, respectively) or patients with cutaneous SLE (parts 2 and 3, respectively). Only parts 1 and 2 are reported here.

Seven cohorts, comprised of 6–9 HV each, were randomized to receive either i.v. (cohorts 1–6) or s.c. (cohort 7) BIIB059 or matching placebo in a 2:1 or 3:1 ratio (Figure 1). Cohorts 1–6 received a single i.v. dose of placebo or 0.05, 0.3, 1, 3, 10, or 20 mg/kg BIIB059. Cohort 7 received a single s.c. dose of placebo or 50 mg of BIIB059. The 12 patients with SLE in cohort 8 were randomized 2:1 to receive a single i.v. dose of placebo (n = 4) or BIIB059 20 mg/kg (n = 8). The study included a 28-day screening period, a 3-day treatment and outpatient observation period (dose administered on day 1), a 16-week follow-up period for both parts 1 and 2, and an additional 12-week extended follow-up period for part 2. The extended follow-up period consisted of telephone calls to subjects for reporting and monitoring SAEs and AEs of interest only.

Eligibility criteria.

Eligible HV were aged 18–55 years inclusive at the time of informed consent, in good health as determined by the investigator, and had a body mass index between 18 and 30 kg/m² and body
weight \geq 45 \text{ kg}. \text{ Eligible patients with SLE in part 2 of the study were aged} \geq 18 \text{ years at the time of informed consent, had an SLE diagnosis according to the 1997 American College of Rheumatology classification criteria for SLE}\ (41), \text{ had a disease duration} \geq 6 \text{ months, had a documented history of antinuclear antibody (titer} \geq 1:80) \text{ or anti-dsDNA antibody prior to screening, and the presence of active lupus skin disease including acute, subacute, and/or chronic cutaneous lupus at the time of screening and randomization and were willing to have at least 2 skin biopsies of the affected skin area. Final CLE diagnosis was adjudicated by 2 dermatologists (VPW and JFM). No specific CLASI-A or SLEDAI-2K score was required at baseline. Patients with active lupus nephritis or active neuropsychiatric SLE were excluded as well as patients at high risk of infections. Stable oral prednisone (or equivalent) at a dose of \leq 15 \text{ mg}, \text{ and treatment with antimalarials, methotrexate (maximum} 20 \text{ mg/week), or azathioprine (maximum} 200 \text{ mg/day), were allowed if the dose regimen was stable for at least 28 days prior to randomization. Other SLE standard of care medications were not allowed.}

**Efficacy assessment.**

In part 2, an exploratory efficacy analyses of SLE disease activity were performed using the CLASI\ (36,37), the SLEDAI-2K\ (35).

**Safety profile.**

Safety endpoints included AEs, AEs of interest (viral infections), serious AEs, vital signs, 12-lead ECG, and laboratory safety assessments, including hematology with complete blood count with
differential and platelet count; blood chemistry (total protein, albumin, creatinine, blood urea nitrogen, uric acid bilirubin total and direct, alkaline phosphatase, alanine aminotransferase, aspartate transaminase, gamma-glutamyl transferase, glucose, calcium, phosphorus, bicarbonate, chloride, sodium, and potassium; urinalysis with dipstick for blood, protein, and glucose (microscopic examination); C-reactive protein; immunophenotyping; white blood cell count (WBC) and absolute differential count of monocytes, neutrophils, and lymphocytes, quantitative immunoglobulins (IgA, IgM, and IgG); complement levels (C3, C4, and Ch50); vaccine titers (tetanus, diphtheria, and pneumococcus); and serum antibodies to BIIB059.

Materials.

BIIB059 (clone 24F4A) is a fully humanized antibody produced in Chinese Hamster Ovary cells as previously described (28). BIIB059 is supplied as a sterile liquid drug product containing 50 mg/mL BIIB059, 10 mM sodium citrate, 140 mM L-arginine hydrochloride, and 0.05% polysorbate-80 at pH 6.0. It is provided in 5-mL vials containing 250 mg of BIIB059 per vial. Mouse IgG1κ-FITC (clone X40, BD Biosciences, Catalog No. 349041); Anti-BDCA2-FITC (clone 2D6, Biogen generated mAb (28). FITC conjugation by BioLegend); Antihuman CD123-PE (clone 9F5, BD Biosciences, Catalog No. 340545); Antihuman HLA-DR-PerCP (clone L243, BD Biosciences, Catalog No. 347364); Antihuman Lineage Cocktail-APC (clones UCHT1, HCD14, 3G8, HIB19, 2H7, HCD56, BioLegend, Catalog No. 348803); BD FACSTM Lysing Solution 10× Concentrate (BD Biosciences, Catalog No. 349202); BD Trucount™ Absolute Counting Tubes (BD
Biosciences, Catalog No. 340334); Quantum MESF FITC Calibration Beads (Bangs Laboratories, Catalog No. 555). Mouse monoclonal anti-CD45 (clone MEM-28 Abcam, Catalog No. ab8216); Mouse monoclonal anti-MxA (clone M143, Prof. Kochs, University Medical Center, Freiburg, Germany,); Rabbit polyclonal anti-IFITM3 (ThermoScientific, Catalog No. Pa5-30382); Rabbit monoclonal anti-CD31 (clone SP38, Spring Bioscience, Catalog No. M3384); Mouse monoclonal anti-CD123 (clone 7G3, BD Biosciences, Catalog No. 554527.

**Methods for BDCA2 expression and pDC count.**

Human whole blood (250 µL) was mixed with fluorochrome-conjugated antibody panels containing either anti-BDCA2 or mouse IgG1κ isotype control. The contents were incubated on ice and in the dark for 30 minutes. Red blood cells were lysed for 10 minutes at room temperature using 5 ml of 1× FACS™ Lysing Solution. Isolated cells were washed twice with 5 ml of PBS + 1% BSA. Following wash steps, cells were resuspended in 500 µL of PBS + 1% BSA and transferred to BD Trucount™ Absolute Counting Tubes. Sample acquisition was performed on a BD FACSCalibur™ flow cytometer (BD Biosciences). For the purpose of standardizing fluorescence intensity, Quantum MESF FITC Calibration Beads were also acquired under the same instrument gain settings at the time of sample acquisition. BDCA2 expression on the pDC population (CD123+ HLA-DR+) was expressed as an MESF value. The absolute number of pDCs (cells/µL) was determined by comparing cellular events with the known number of fluorescent beads present in the BD Trucount™ Absolute Counting Tubes.
Antibody cocktail panels

Mouse IgG1κ-FITC or BDCA2-FITC CD123-PE HLA-DR-PerCP; Lineage Cocktail (CD3, CD14, CD16, CD19, CD20, CD56)-APC.

IFN signature assays.

RNA isolation and reverse transcription

Blood was collected in PAXgene Blood RNA Tubes (BD Biosciences) and stored at -20°C until ready for use. Intracellular RNA was isolated using the PAXgene Blood RNA Kit (BD Biosciences) and quantified using a NanoDrop spectrophotometer (Thermo Fisher Scientific). RNA was normalized to 20 ng/ml and then reverse transcribed using a High Capacity cDNA Reverse Transcription Kit (Thermo Fisher Scientific).

Real-time PCR gene expression analysis

The expression of 37 genes associated with IFN activity was analyzed using the BioMark HD System (Fluidigm). Owing to the number of assays, expression analysis for each sample was performed across 2 separate runs using independent assay panels. The first panel contained 26 assays as well as assays for 4 house-keeping genes (ACTB, GAPDH, UBC, and YWHAZ) while the second panel contained 11 assays and 3 house-keeping gene assays (UBC, YWHAZ, and B2M). Custom Taqman Expression Assays (Thermo Fisher Scientific) and samples were prepared according to Fluidigm recommendations and loaded into 96.96 Dynamic Array Integrated Fluidic Circuits (IFC; Fluidigm). Samples were loaded singly, and assays were loaded in triplicate.
IFC plates were primed and loaded using the Controller HX (Fluidigm) and then transferred to the BioMark HD for real-time PCR data collection. The following thermocycling program was used: 70°C for 30 minutes, 25°C for 10 minutes, 95°C for 1 minute followed by 45 cycles of 96°C for 5 seconds and 60°C for 20 seconds.

Sample data were normalized to the mean house-keeping gene value for each run, and any sample with a standard deviation >0.3 C_t was omitted from analysis. An endogenous quality control (EQC) was prepared for each assay panel and used to evaluate run acceptance. Panel 1 EQC was prepared by combining cDNA from 4 SLE donors while panel 2 EQC was prepared by combining cDNA from 3 SLE donors and 2 Sjögren’s donors. Each EQC was preamplified 10× and then diluted into the appropriate range for the assay. The performance of each EQC was evaluated over 5 independent runs and acceptance criteria for each assay were set at ±0.3 ΔC_t from the mean ΔC_t of each EQC assay result.

**PK methods**

**PK assay**

The assay to quantify BIIB059 in serum samples is a sandwich ELISA that utilizes a BIIB059 anti-idiotypic antibody as capture reagent and HRP-mouse antihuman IgG Fc conjugate for detection. Substrate (3,3’,5,5’-tetramethylbenzidine) is added to plate wells and color development is subsequently stopped by the addition of 1N sulfuric acid. OD_450 is read on a
plate reader and concentrations are determined by interpolation from a standard curve using 5-parameter curve fit.

**Dose selection and PK methods**

The starting dose of 0.05 mg/kg (i.v. infusion) was expected to have a low pharmacological response based on the estimated human *in vivo* drug concentration that resulted in 10% of maximal response (EC<sub>10</sub>) for BDCA2 internalization and the projected human observed C<sub>max</sub>. The mean EC<sub>10</sub> value from preclinical experiments in cynomolgus monkeys was approximately 0.064 µg/ml. To account for the 2-fold higher frequency of pDCs in humans and 8-fold higher BDCA2 density on human pDCs compared with cynomolgus monkeys, the estimated human *in vivo* EC<sub>10</sub> for BDCA2 internalization was approximately 1.03 µg/ml. A BIIB059 serum concentration profile following a single 0.05 mg/kg dose (for 70 kg body weight) via a 30-minute i.v. infusion was simulated and gave a projected human C<sub>max</sub> of approximately 1.12 µg/ml. Because this was similar to the estimated human *in vivo* EC<sub>10</sub> for BDCA2 internalization (1.03 µg/ml), this starting dose was expected to have a low pharmacological response in humans and therefore was the appropriate starting dose for the single ascending dose part of the study. Furthermore, substantial safety margins (relative to the no observed adverse effect level [NOAEL] of 125 mg/kg i.v. in cynomolgus monkey) of approximately 1000- to 3600-fold were expected with this starting dose.
The planned maximum dose in parts 1 and 2 was a 20 mg/kg i.v. infusion. This dose was selected to ensure adequate characterization of the safety and tolerability of single ascending doses of BIIB059 with the aim of identifying the maximum tolerated dose, if feasible. Based on the projected $C_{\text{max}}$ and $AUC_{\infty}$, the safety margins for this planned maximum dose (relative to the NOAEL of 125 mg/kg i.v.) were approximately 2.5- to 9-fold.

A fixed s.c. dose (50 mg at a concentration of 50 mg/ml) rather than a body weight–based s.c. dose was chosen to minimize the variability in the injection volume of BIIB059.

**PK parameter estimation method**

All subjects with observed PK concentrations sufficient for estimating the PK parameters were included in the PK analyses. Pharmacokinetic parameters for BIIB059 were estimated on the basis of standard noncompartmental methods using Phoenix version 6.2 (Certara Corporation, Mountain View, California) software package. The $C_{\text{max}}$ and $t_{\text{max}}$ were determined directly from the plasma concentration-time profile for BIIB059. The terminal phase elimination rate constant ($\lambda_z$) was estimated by log-linear regression of concentration-time data in the terminal portion of the PK profiles. $t_{1/2}$ was estimated as $\ln(2)/\lambda_z$. The AUC from zero time to last observed time point ($AUC_t$) was calculated using the trapezoidal rule. The AUC extrapolated from the last data point to infinity ($AUC_{t-\infty}$) was estimated by dividing the concentration at the last point by the elimination rate constant ($\lambda_z$). The total AUC ($AUC_{\infty}$) was calculated as $AUC_t + AUC_{t-\infty}$. The clearance (CL) and volume of distribution ($V_z$) were calculated as $CL = \text{dose}/AUC_{\infty}$ and $V_z = (CL)/\lambda_z$ (for s.c. dosing it is estimated as $CL/F$ and $V_z/F$). The relative
bioavailability was estimated by comparing the AUC values following administration of single i.v. (1 mg/kg) and s.c. (50 mg) dose of BIIB059.

**IHC methods**

Four to six mm punch biopsies in formalin from affected and paired unaffected skin were received from the 12 patients with SLE. Biopsies were examined and bisected by a pathologist, then processed into paraffin blocks. H&E-stained sections at various intervals were examined to ensure that IHC was performed on sections within lesions. Punch biopsies of 4 mm were collected from sun-exposed skin of HVs matched approximately by age and ethnicity to the BIIB059-treated cohort (mean age = 34; range [28–37]; White 6/8; Asian 1/8; Black or African American 1/8); female 8/8) by Folio Biosciences, then processed into paraffin blocks for transfer to Biogen. IHC for MxA, IFITM3, CD45, and dual IHC for CD123/CD31 was performed on 1 section from each specimen on Ventana Discovery Ultra or Ventana Discovery XT automated staining instruments.

Slides were digitized with a Panoramic P250 scanner at 200X resolution, and skin biopsies were hand-annotated to define epidermis, papillary dermis, and reticular dermis; follicular epithelium and adnexa were included with epidermis, sebaceous glands were excluded. Using a combination of color deconvolution and median filters, customized image analysis algorithms were generated in Visiopharm to distinguish immunopositive areas from immunonegative tissue. Subsequently, percentage area values were calculated for each biomarker and sample. CD123 was quantified by first excluding pixels also immunopositive for CD31 to differentiate
capillaries from pDCs. IHC and image analysis of the HV cohort specimens were performed ~2 years after the BIIB059/placebo specimens. Ab, Ab lots, and IHC and image analysis protocols used on HV specimens were matched, and assay variation for epidermal MxA protein was found to be 7%, well within the accepted variation range for this assay.

**Statistics**

The safety analysis set included all the subjects who were randomized and received at least 1 dose of BIIB059 or placebo. The PD analysis set included all the subjects who were randomized and received at least 1 dose of BIIB059 or placebo and had at least 1 post-dose sample biomarker or other data collected. The PK analysis set included all individuals in the safety analysis set for whom at least 1 primary PK parameter could be calculated. The study was not powered for any formal testing, but the sample size of this study was considered sufficient to characterize the single-dose and multiple-dose safety, tolerability, and PK and PD profiles of BIIB059. The association between log2-fold change of MxA and % change of CLASI-A was assessed by Spearman’s correlation. No formal hypothesis testing was performed. The upper limit of the normal range was determined by taking the maximum percentage area immunoreactivity in a skin compartment for the healthy volunteer cohort rounded to the nearest 0.1%.
Study approval

Informed consent was obtained from all subjects in accordance with the human subjects Institutional Review Boards of all the participating centers. The study was performed in accordance with the Declaration of Helsinki, the International Conference on Harmonization Note for Guidance on Good Clinical Practice (ICH Topic E6, 1996).
**Author contributions**

RF designed and conducted the study, analyzed the data, and edited the manuscript. VPW and JFM designed the study, analyzed the data, and edited manuscript. LS, TLR, WW, AG, and PG designed the experiments, analyzed the data, and edited the manuscript. HN, RC, and CB analyzed the data and edited the manuscript. AP designed the experiments and edited the manuscript. SH and PA designed and/or performed experiments, and analyzed the data. DR designed the experiments, analyzed the data, and wrote the manuscript. NF designed the study, designed the experiments, analyzed the data, and edited the manuscript. All authors critically reviewed the manuscript.

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REFERENCES


**Figure 1. Study design.** Single ascending dose in the healthy volunteer cohorts and single dose in the systemic lupus erythematosus (SLE) cohort.
Figure 2. BIIB059 pharmacokinetic (PK) profile in healthy volunteers (HV) and a cohort of patients with systemic lupus erythematosus (SLE) with active cutaneous lupus. BIIB059 serum levels were measured using ELISA. (A) PK of single ascending dose of BIIB059 in HV n=38 and (B) PK of 20 mg/kg BIIB059 in HV (black line) n=6 and patients with SLE (red line) n=8. Arithmetic mean values are represented.
Figure 3. BIIB059 demonstrates pharmacokinetic (PK) and pharmacodynamic (PD) correlations in both healthy volunteers (HV) and a cohort of patients with systemic lupus erythematosus (SLE). (A and B) BDCA2 levels on plasmacytoid dendritic cells (pDCs) as the median % change in BDCA2 level normalized to baseline level in HV PBO cohort (n=16), HV, BIIB059 treated cohort (n=38), SLE PBO (n=4), SLE BIIB059 treated cohort (n=8); fluorescent-labeled non-cross-blocking anti-BDCA2 mAb (2D6) was used to label surface BDCA2 on the pDC population (CD123+ HLA-DR+) in whole blood using flow cytometry. (C and D) PK/PD relationship between BIIB059 serum concentrations (red triangle, left axis) and BDCA2 expression on pDCs (black squares, right axis, normalized to baseline levels). Panel C depicts a representative HV from the 3 mg/kg dose group (n=6). Panel D depicts a representative patient with SLE (20 mg/kg), n=8.
Figure 4. Single dose of BIIB059 in patients with systemic lupus erythematosus (SLE) dampens the expression of IFN response genes (IRG) in whole blood. Whole blood was collected in PAXgene Blood RNA Tubes. After RNA isolation the expression of IRG was analyzed using the Fluidigm BioMark HD System. The ratio from baseline is shown for (A) placebo and (B) BIIB059 treatment of patients with SLE C. Percentage change from baseline of the IFN score based on the 9 IRGs in individual patients. *Subject 1 initiated steroid treatment during the study.
Figure 5. BIIB059 leads to decrease in the IFN response in the skin, which correlates with improvement in CLASI-A score. (A and B) Skin biopsies from active lesions were evaluated at baseline (day -1) and week 4 post-treatment with 20mg/kg BIIB059 for MxA protein expression using quantitative IHC on formalin-fixed 4–5mm punch biopsies. Representative photomicrographs and % area of epidermal MxA-positive immunoreactivity are shown for each patient in the placebo group (A) and the BIIB059-treated group (B). CLASI-A scores were evaluated on day -1, week 4, and week 12 post-treatment for placebo-treated (A) and BIIB059-treated (B) patients with SLE. Response is defined as a ≥4-point reduction from baseline in CLASI-A score at week 4 and/or week 12. Responders are depicted in green, non-responders in red. (C) Correlation plot of percentage change in MxA expression from baseline and percentage CLASI-A score change from baseline for all patients (placebo treated [circle] and BIIB059 treated [triangle]). (D) CLASI-A response over time; CLASI-A responders are depicted in green, non-responders in red. *Subject 1 initiated steroid treatment during the study. ACLE, acute cutaneous lupus erythematosus; CLE, cutaneous lupus erythematosus; CLASI-A, Cutaneous Lupus Erythematosus Disease Area and Severity Index Activity; DLE, discoid lupus erythematosus; ND, not determined; NR, no response; R, response; SCLE, subacute cutaneous lupus erythematosus; SLE, systemic lupus erythematosus.
### Table A

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### Graph C

**Log2 fold change of MxA (Epidermis)**

- Treatment group
  - BIIB059
  - Placebo

**% change of CLASI-A score at week 4**

### Graph D

**PBO**

- CLASI-A score over time:
  - Day 1: [Graph Data]
  - Wk 4: [Graph Data]
  - Wk 12: [Graph Data]

**BIIB059**

- CLASI-A score over time:
  - Day 1: [Graph Data]
  - Wk 4: [Graph Data]
  - Wk 12: [Graph Data]
Figure 6. BIIB059 normalizes MxA expression and reduces cellular infiltration in skin lesions of patients with SLE. Representative photomicrographs of IHC from patient 5 (A) MxA protein (also shown in Figure 5B) and (C) CD45+ cells. HV (top panel), pre-dose patient 5 (lower left panel), week 4 post-BIIB059 (lower right panel). (B and D) Percent area of immunoreactivity of MxA protein and CD45 in placebo- (PBO) and BIIB059-treated patients pre-dose (day -1) and 4 weeks post-dose. Healthy range was determined using biopsies from 8 HV; dotted line delineates the healthy range. Responders are depicted with a black line, non-responders with a red line.
Figure 7. Model of BIIB059 mechanism of action in cutaneous lupus erythematosus (CLE). (A) In CLE, plasmacytoid dendritic cells (pDCs) accumulate in skin lesions and produce IFN-λ and IFN-α (large arrow) as detected by the upregulation of the IFN-responsive protein MxA in the epidermis. pDCs also secrete a broad range of cytokines and chemokines, which in addition to IFN-λ may support the recruitment of inflammatory cells into the lesions (depicted by CD45+ cells). (B) Treatment with BIIB059 leads to the functional inhibition of pDCs and the dampening of IFN-λ and likely other inflammatory mediators, resulting in decreased MxA expression, reduction in immune cellular infiltrates, and amelioration of disease activity in CLE lesions.
Table 1. Baseline characteristics of study participants: Part 1: Healthy volunteers

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Table 2. Baseline characteristics of study participants: Part 2: Patients with SLE

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<tr>
<td>Female sex, n (%)</td>
<td>4 (100)</td>
<td>8 (100)</td>
<td>12 (100)</td>
</tr>
<tr>
<td>Race, n (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Black/African American</td>
<td>2 (50)</td>
<td>1 (13)</td>
<td>3 (25)</td>
</tr>
<tr>
<td>White</td>
<td>2 (50)</td>
<td>6 (75)</td>
<td>8 (67)</td>
</tr>
<tr>
<td>Asian</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>American Indian/Alaskan native</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Other</td>
<td>0</td>
<td>1 (13)</td>
<td>1 (8)</td>
</tr>
<tr>
<td>Body weight, kg, mean (SD)</td>
<td>73.6 (14.5)</td>
<td>68.9 (9.8)</td>
<td>70.5 (11.2)</td>
</tr>
<tr>
<td>Body mass index, kg/m(^2), mean (SD)</td>
<td>27.0 (6.9)</td>
<td>24.6 (3.2)</td>
<td>25.4 (4.6)</td>
</tr>
<tr>
<td>CLE classification (A/S/C)(^a)</td>
<td>0/2/2</td>
<td>4/1/3</td>
<td>4/3/5</td>
</tr>
<tr>
<td>CLASI-A score, mean (SD)</td>
<td>16.3 (19.2)</td>
<td>10.4 (5.4)</td>
<td>12.3 (11.3)</td>
</tr>
<tr>
<td>SLEDAI-2K score mean (SD)</td>
<td>7.5 (3.4)</td>
<td>5.9 (4.7)</td>
<td>6.4 (4.2)</td>
</tr>
<tr>
<td>Antinuclear antibody, n (%)</td>
<td>4 (100)</td>
<td>8 (100)</td>
<td>12 (100)</td>
</tr>
<tr>
<td>Anti-dsDNA</td>
<td>0</td>
<td>1 (13)</td>
<td>1 (8)</td>
</tr>
<tr>
<td>Anti-Smith</td>
<td>0</td>
<td>2 (25)</td>
<td>2 (17)</td>
</tr>
<tr>
<td>Anti-SSA</td>
<td>2 (50)</td>
<td>7 (88)</td>
<td>9 (75)</td>
</tr>
<tr>
<td>Anti-SSB</td>
<td>0</td>
<td>1 (13)</td>
<td>1 (8)</td>
</tr>
<tr>
<td>Anti-RNP</td>
<td>2 (50)</td>
<td>5 (63)</td>
<td>7 (58)</td>
</tr>
</tbody>
</table>
### Concomitant Medications, n (%)

<table>
<thead>
<tr>
<th>Medication</th>
<th>A: Acute CLE</th>
<th>S: Subacute CLE</th>
<th>C: Chronic CLE Including DLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antimalarials&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1 (25)</td>
<td>2 (25)</td>
<td>3 (25)</td>
</tr>
<tr>
<td>Azathioprine</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Methotrexate</td>
<td>0</td>
<td>1 (13)</td>
<td>1 (8)</td>
</tr>
<tr>
<td>Topical steroids</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Oral corticosteroids&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0</td>
<td>2 (25)</td>
<td>1 (17)</td>
</tr>
</tbody>
</table>

<sup>A</sup> A: acute CLE; S: subacute CLE; C: chronic CLE including DLE.  
<sup>b</sup> Antimalarial medications include hydroxychloroquine/Plaquenil, chloroquine/Aralen, and quinacrine.  
<sup>c</sup> Oral corticosteroids include prednisone, methylprednisolone/Medrol, prednisolone, dexamethasone/Decadron, hydrocortisone, and cortisol. CLASI-A, Cutaneous Lupus Erythematosus Disease Area and Severity Index Activity; CLE, cutaneous lupus erythematosus; DLE, discoid lupus erythematosus; N/A, not applicable; SLE, systemic lupus erythematosus.
Table 3. Safety summary: Part 2 (Patients with systemic lupus erythematosus)

<table>
<thead>
<tr>
<th>Subjects, n (%)</th>
<th>Placebo</th>
<th>BIIB059</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dosed</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>With any AE</td>
<td>3 (75)</td>
<td>7 (88)</td>
</tr>
<tr>
<td>Moderate event</td>
<td>2 (50)</td>
<td>4 (50)</td>
</tr>
<tr>
<td>Severe event</td>
<td>1 (25)</td>
<td>1 (13)</td>
</tr>
<tr>
<td>Related event</td>
<td>1 (25)</td>
<td>1 (13)</td>
</tr>
<tr>
<td>Serious event / related serious event</td>
<td>0/0</td>
<td>1 (13)</td>
</tr>
<tr>
<td>Discontinuation / withdrawal due to event</td>
<td>0/0</td>
<td>0/0</td>
</tr>
</tbody>
</table>

AE, adverse event.
Table 4. PK parameters

<table>
<thead>
<tr>
<th>Variable, mean</th>
<th>Healthy volunteers</th>
<th>Patients with SLE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.05 mg/kg</td>
<td>0.3 mg/kg</td>
</tr>
<tr>
<td>(%CV)</td>
<td>i.v.</td>
<td>i.v.</td>
</tr>
<tr>
<td></td>
<td>119</td>
<td>1865</td>
</tr>
<tr>
<td>AUC(_t), hr•µg/ml</td>
<td>(50.8)</td>
<td>(36.8)</td>
</tr>
<tr>
<td>AUC(_\infty), hr•µg/ml</td>
<td>(NC)</td>
<td>(45.5)</td>
</tr>
<tr>
<td>C(_{max}), µg/ml</td>
<td>1.68</td>
<td>10.9</td>
</tr>
<tr>
<td></td>
<td>(9.8)</td>
<td>(25.4)</td>
</tr>
<tr>
<td>t(_{max}), hours</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>t(_{1/2}), days</td>
<td>3.5</td>
<td>8.5</td>
</tr>
<tr>
<td></td>
<td>(27)</td>
<td>(38.8)</td>
</tr>
</tbody>
</table>