Recovery of HLA-Restricted Cytomegalovirus (CMV)-Specific T-Cell Responses After Allogeneic Bone Marrow Transplant: Correlation With CMV Disease and Effect of Ganciclovir Prophylaxis

By Cheng-Rong Li, Philip D. Greenberg, Mark J. Gilbert, James M. Goodrich, and Stanley R. Riddell

Protection from cytomegalovirus (CMV) disease in immunocompromised hosts has been shown to correlate with recovery of the host virus-specific CD8+ T-cell response. The administration of ganciclovir to immunosuppressed transplant recipients as antiviral prophylaxis has reduced the early risk of CMV disease, but late disease is observed with increased frequency, suggesting that recovery of the CMV-specific T-cell responses necessary for protective immunity may be delayed in these patients. Therefore, we evaluated reconstitution of CMV-specific T-cell responses in 47 bone marrow transplant (BMT) recipients entered on a randomized placebo-controlled study of ganciclovir. The study drug was initiated at a mean of 24 days after BMT. At day 30 to 40, a minority of patients had recovery of T-cell immunity to CMV and the frequency of reconstitution was equivalent in patients randomized to ganciclovir or placebo. The failure of ganciclovir to effect early reconstitution may reflect the short duration of treatment. Early recovery was associated with the infusion of BM from a CMV seropositive donor (P = .07 for CD8+ cytotoxic T cell (CTL), P = .04 for CD4+ Th). Between day 40 and day 90, recovery of deficient CD8+ and CD4+ CMV-specific T-cell responses occurred in the majority of individuals that received placebo, but in a minority of ganciclovir recipients. Two cases of late-onset CMV disease occurred in ganciclovir recipients. In all patients, the presence of a CTL response to CMV conferred protection from subsequent CMV disease (P = .005), and these protective CTL responses are shown to be specific for structural virion proteins similar to the responses in immunocompetent CMV seropositive individuals. These data confirm the importance of CMV-specific T-cell responses and suggest that a delay in recovery of these responses as a result of ganciclovir prophylaxis may contribute to the occurrence of late CMV disease.

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Healthy Cytomegalovirus (CMV) seropositive individuals maintain CD8+ and CD4+ HLA-restricted T-cell responses to CMV and suffer no apparent consequences from lifelong CMV infection.1-4 By contrast, individuals with compromised immunity, including allogeneic bone marrow transplant (BMT) recipients, solid organ transplant recipients, and patients with the acquired immunodeficiency syndrome are at risk of developing life-threatening CMV disease after reactivation or primary infection with CMV.5-7 Studies of immune reconstitution after allogeneic BMT have shown a temporal delay in the recovery of CMV-specific T-cell responses and have identified a decisive role for the recovery of CD8+ class I HLA-restricted CTL responses in preventing the development of CMV disease.8-10 In these studies, the recovery of CD4+ Th appears to be obligatory for the generation of CD8+ CMV-specific CTL, reflecting a requirement for adequate host Th function for efficient induction and expansion of CD8+ CTL responses.5 Thus, factors that delay the reconstitution of either CD4+ Th or CD8+ CTL after BMT would prolong the period of risk for CMV disease.

The use of ganciclovir as early treatment after detection of CMV in the blood or bronchoalveolar lavage fluid and as prophylaxis for CMV infection in BMT and heart transplant recipients has dramatically reduced the incidence of CMV disease in these immunocompromised hosts.11-15 Early treatment and prophylaxis strategies have not been uniformly successful; up to 15% of BMT recipients have developed CMV disease after discontinuation of antiviral therapy and patients undergoing lung transplantation have been found to be only transiently protected.11,13,16 The occurrence of CMV disease after the cessation of ganciclovir prophylaxis has also been observed with murine CMV infection in immunosuppressed mice.17 These results suggest that the CMV-specific T-cell responses necessary for protection may not recover during the time the host is receiving antiviral therapy. This could reflect a general inhibitory action of ganciclovir on T cells as previously shown in vitro or a selective effect on the in vivo recovery of HLA-restricted CMV-specific T-cell responses.18,19 Ganciclovir exerts its antiviral effects at the stage of viral DNA replication; therefore, in the presence of the drug, infected cells may express immediate early (IE) and early (E) gene products, but not the full repertoire of CMV genes necessary for replication and new virion formation.20 In latent CMV seropositive individuals, the class I HLA-restricted CD8+ cytotoxic T-cell (CTL) response to CMV is predominantly specific for epitopes derived from structural virion proteins and these antigens are presented rapidly after entry of virions into the cytoplasm.4 Thus, in individuals receiving ganciclovir, the viral antigens available may not be adequate to activate host T-cell responses resulting in the failure to reconstitute CMV-specific CD4+ Th and CD8+ CTL, or responses specific for IE or E viral gene products may be preferentially activated and these CTL may not be sufficient to provide protective immunity.

In this report, the temporal kinetics of endogenous recon-

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stitution of CD4+ and CD8+ HLA-restricted CMV-specific T-cell responses were evaluated in 47 allogeneic BMT recipients entered onto a double-blind randomized trial in which individuals received ganciclovir or placebo prophylaxis after recovery of peripheral neutrophil counts. The data show that the recovery of CD4+ and CD8+ CMV-specific T-cell responses early after BMT is more frequently observed in recipients of BM from CMV seropositive donors consistent with the transfer of primed T cells in the marrow inoculum contributing to CMV-specific immune recovery in these recipients. The results confirm previous studies showing that recovery of CD8+ CMV-specific CTL responses confers protection from CMV disease in BMT recipients not receiving ganciclovir prophylaxis. This observation is extended to show that the protective CD8+ CTL responses that develop after BMT are specific for structural virion proteins, similar to the immunodominant response maintained in healthy CMV-seropositive individuals.4 The data also show that patients receiving ganciclovir prophylaxis have delayed recovery of HLA-restricted CMV-specific T-cell responses including CD8+ CTLs, a finding that may explain the cases of late-onset CMV disease observed in BMT and lung transplant recipients receiving ganciclovir prophylaxis.3,11,13,16

MATERIALS AND METHODS

Patient population. Forty-seven CMV seropositive patients undergoing allogeneic BMT at the Fred Hutchinson Cancer Research Center were randomly assigned to receive ganciclovir or placebo as prophylaxis for CMV infection. These patients represent a random sample of a larger number of patients entered onto a study evaluating the antiviral effects of ganciclovir prophylaxis. The results of the efficacy and toxicity of ganciclovir prophylaxis in the entire study group has been published.13 The study was approved by the Institutional Review Board and all patients gave informed consent. Patients were evaluated for recovery of CMV-specific T-cell responses between days 30 and 40, and between days 80 and 90 after transplant. In one patient in the ganciclovir group, the second evaluation was not done until day 125. Eight of the patients died or relapsed and one patient withdrew from the study before the first evaluation of CMV-specific T-cell responses. Four patients were studied for CMV-specific T-cell reconstitution, but at the time of randomization, were excluded from receiving the study drug because of renal failure (N = 2), or a positive pretransplant CMV culture (N = 2). The nonrandomized patients did not receive ganciclovir unless CMV disease developed. Thirty-four patients received the study drug with 15 receiving ganciclovir and 19 receiving placebo. The clinical characteristics of these patients are shown in Table 1. Prophylaxis for graft-versus-host disease (GVHD) was similar in both groups with the majority of patients receiving methotrexate and cyclosporine. The severity of acute GVHD was graded according to published criteria.21 The randomization code was not broken until the study was completed.

CMV-specific CTL generation. Short-term CMV-specific CTL lines were generated as previously described.4,22 Briefly, skin biopsies were obtained from each marrow donor to establish a fibroblast line for use as stimulator and target cells. Fibroblasts were propagated in Waymouth’s media supplemented with 15% fetal calf serum, penicillin (50 U/mL) and streptomycin (50 µg/mL). Peripheral blood mononuclear cells (PBMC) were obtained from the BMT recipient and cultured at a responder to stimulator ratio of 20:1 with HLA-identical fibroblasts derived from the marrow donor and infected for 6 hours with AD169 strain CMV at a multiplicity of infection (MOI) of 5. Although the lymphocyte yield varied amongst patients, there was no significant difference in the mean number of lymphocytes between the placebo and ganciclovir groups. The T-cell culture media was RPMI 1640 supplemented with 10% human AB positive, CMV seronegative serum, 2 mmoL/L glutamine, penicillin (50 U/mL), streptomycin (50 µg/mL), and 2.5 × 10−8 mol L 2-mercaptoethanol. The T-cell cultures were stimulated again 7 days later with fresh CMV-infected fibroblasts and supplemented with autologous irradiated (3,300 rads) PBMC as feeder cells, and fed with recombinant interleukin-2 (IL-2) (2 U/mL), and 2 days after restimulation. Fibroblasts express abundant class I HLA molecules; thus, when used as stimulators, CD3+, CD8+, CD4- class I-restricted CTL precursors present in PBMC are preferentially activated and expanded.14,15,22−23 The use of IFNγ pretreatment of target cells has been shown to increase the sensitivity of the assay for the detection of CD8+ CMV-specific CTL.23 CMV-infected fibroblasts are lysable by CD8+ CTLs,4 and unpublished data, November 1992. Spontaneous chromium release was determined from target cells incubated with media and maximum release from target cells incubated with 1% NP-40. In all experiments, spontaneous release was less than 25% of maximal release. Specific lysis was calculated by the standard formula. A CTL response in the patients was defined as positive if the cultures showed lysis of HLA identical CMV-infected targets at least 10%.
greater than the level of lysis observed with HLA-identical mock-infected and HLA class I-mismatched CMV-infected and mock-infected target cells. This definition of a positive response is based on the results of cultures from six consecutive CMV seronegative normal individuals. These cultures from seronegative individuals all showed less than 2% greater lysis of autologous CMV-infected target cells than the lysis observed against either mock-infected or HLA-mismatched CMV-infected target cells (unpublished data, August 1993).

In a subset of recipients with demonstrable CD8+ CMV-specific CTL activity, the specificity of CTL responses for structural virion proteins was examined by assaying for lysis of HLA-identical and HLA-mismatched target cells infected with CMV in the presence of actinomycin D as previously described. In selected patients where sufficient T cells were available after culture, the phenotype of the cytolytic effector cell was confirmed by depleting CD4+ T cells or CD8+ T cells using tissue-culture flasks coated with either anti-CD4 or anti-CD8 monoclonal antibodies (MoAbs) (Applied Immune Sciences, Menlo Park, CA). This method results in 90% to 95% depletion of the selected T-cell subset (data not shown).

**Lymphoproliferation assay.** The CD4+ T lymphoproliferative response of PBMC to soluble CMV antigen, a control antigen, and to phytohemagglutinin (PHA) (Difco Laboratories, Detroit, MI) was determined at the time CTL cultures were initiated. The coculture of PBMC with CMV antigen has been shown to selectively expand and expand CD4+ class II HLA-restricted T cells presumably because there is no cell in PBMC sufficiently permissive for CMV infection to present viral antigen via the class I antigen-processing pathway, but there is uptake and presentation of viral antigen by antigen-presenting cell via the class II pathway to elicit CD4+ T helper cell proliferative responses. Thus, depletion of CD4+ T cells before initiating the cultures or blocking with anti-class II HLA MoAbs abrogates or inhibits the proliferative response of PBMC from normal CMV seropositive individuals, and (unpublished data, November 1992). One hundred microliters of PBMC (1 x 10^6 cells) in T-cell culture media was dispensed in triplicate wells of 96-well-round-bottom plates. Mock antigen, CMV and PHA were added at final concentrations of 1:200, 1:200, and 10 μg/mL respectively, whereas control triplicates received media alone. The cultures were pulsed with 1 μCi per well of 3H thymidine for the final 16 hours of a 96-hour incubation. Wells were harvested and incorporation of 3H thymidine determined by beta scintillation counting. Results are expressed as a stimulation index (SI) by dividing the mean counts per minute (CPM) incorporated by cells exposed to CMV or PHA by the mean CPM of cells exposed to control antigen. A stimulation index of greater than 1.5 was considered to indicate a positive lymphoproliferative response. This was determined by prior analysis of ten CMV seronegative individuals in whom the mean SI was 0.9 (range 0.5 to 1.2) with this CMV antigen preparation and identical culture conditions (unpublished data, November 1992 and August 1993).

**Study drug administration.** The study drug (ganciclovir or placebo) was initiated after recovery of the absolute neutrophil count to greater than 750/mm³ for 2 consecutive days. Ganciclovir was administered at a dose of 5 mg per kg twice daily for the first 7 days and then once daily until 100 days after transplant. The study drug was discontinued if the neutrophil count fell below 750/mm³ for 2 consecutive days.

**Virologic surveillance and definition of CMV disease.** Specimens were obtained weekly from the throat, urine, and blood and were examined for CMV by conventional culture in which specimens were inoculated onto monolayers of human fibroblasts and by centrifugation culture. CMV pneumonia was defined as evidence of CMV in bronchoalveolar lavage associated with clinical signs and symptoms; CMV disease at other sites was defined by evidence of CMV in tissue sections associated with clinical signs and symptoms.

**Statistical analysis.** Comparisons of dichotomous variables were analyzed using Fisher's exact test.

## RESULTS

Recovery of CD8+ and CD4+ CMV-specific T-cell responses at days 30 to 40 after BMT. To determine the kinetics of recovery of CMV-specific T-cell responses in patients entered onto this placebo-controlled study of ganciclovir prophylaxis, patients were analyzed on two occasions for the presence of CD8+ class I HLA-restricted and CD4+ class II HLA-restricted CMV-specific T-cell responses. Blood samples were first obtained and assayed between days 30 and 40 after the BMT. At this time all patients had evidence of marrow engraftment as defined by an absolute neutrophil count of greater than 750/mm³ and had been randomized to study drug or excluded from randomization according to the protocol. The mean day of initiating study drug was 24 (range 14 to 36). CD8+ class I HLA-restricted CMV-specific CTL responses were evaluated by stimulating PBMC with HLA-identical CMV-infected fibroblasts that express class I HLA, but not class II HLA molecules and selectively activate CD8+ CTL precursors. CD8+ CMV-specific CTL were detected in 4 of 19 (21%) and 4 of 15 (26%) patients randomized to placebo and ganciclovir respectively (Table 2). CTL responses were detected in 1 of 4 (25%) patients who were initially entered on study, but were not randomized at the time of engraftment because of renal failure or a positive pretransplant CMV culture.

In the eight patients randomized to ganciclovir or placebo and with detectable CTL responses, the cytolytic reactivity observed was class I HLA restricted as shown by lysis of HLA-identical CMV-infected cells, but not class I HLA-mismatched target cells (Fig 1). In a subset of these patients, selective depletion of either CD4+ T cells or CD8+ T cells confirmed that the effector cell responsible for lysis was CD8+ and not CD4+ (Fig 2). The mean lytic activity at an effector to target ratio of 15:1 was 32% ± 10.3% (range 25% to 49%) for ganciclovir recipients and 22% ± 5.8%
Positive Th responses were detected in all patients that had CD8+ CTL responses. The mean stimulation index for CMV-specific CD4+ Th responses in the placebo group was 10.1 ± 13.8 (range 1.6 to 45.1) and in the ganciclovir group was 13.2 ± 14.4 (range 1.8 to 46.8) (Table 2). Thirty-three of the 34 patients randomized to ganciclovir or placebo and 4 of 4 nonrandomized patients had a positive proliferative response to PHA with a mean stimulation index of 88.1 ± 64 (range 3.7 to 378) for placebo recipients, 99.1 ± 82.4 (range 2.1 to 294) for ganciclovir recipients, and 70.8 for nonrandomized patients. Thus, the similar numbers of patients recovering detectable CMV-specific immune responses in the ganciclovir and placebo groups shows that administration of ganciclovir after engraftment has no discernible impact on CMV-specific T-cell recovery when analyzed within 7 to 14 days after initiation of the drug.

Influence of marrow donor serology on early reconstitution of CMV-specific T-cell responses. The analysis at day 30 to 40 showed that early recovery of CMV-specific T-cell responses is observed in only a minor subset of patients. This may reflect the transfer of primed antigen-specific T cells in the marrow inoculum as has been shown for CD4+ Th responses to nonviral antigens. The recovery of CMV-specific CD8+ CTL and CD4+ Th responses at days 30 to 40 after BMT was analyzed in relationship to donor CMV serology for the 34 patients randomized to ganciclovir or placebo recipients at day 30 to 40 after transplant. Cytotoxic T-cell responses were generated from peripheral blood lymphocytes isolated from recipients by stimulation with donor-derived HLA-identical fibroblasts as described in Materials and Methods. These cultures were assayed for recognition of HLA-matched CMV-infected (■) and mock-infected (□), and class I HLA-mismatched CMV-infected (□) and mock-infected (○) targets. Each recipient is identified by a unique patient number and the data are shown for each recipient at an effector to target ratio of 15:1. The data in (A) shows the responses observed in individuals randomized to placebo and the data in (B) show the responses in individuals randomized to ganciclovir.

(range 14% to 29%) for patients randomized to placebo (Fig 1). At days 30 to 40, CD4+ CMV-specific Th responses were evaluated by stimulating PBMC with CMV antigen, which elicits CD4+ class II HLA-restricted Th responses. Responses were detected in 8 of 19 (42%) and 8 of 15 (53%) patients randomized to placebo and ganciclovir, respectively, and in 2 of the 4 (50%) nonrandomized patients (Table 2).
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Table 3. Influence of Donor CMV Serology on HLA-Restricted CMV-specific T-Cell Reconstitution at Day 30 to 40 After BMT

<table>
<thead>
<tr>
<th>Donor Serostatus</th>
<th>CMV Positive</th>
<th>CMV Negative</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>CD8' CTL recovery</td>
<td>8/22 (36%)</td>
<td>1/16 (6%)</td>
<td>.07</td>
</tr>
<tr>
<td>CD4' Th recovery</td>
<td>14/22 (64%)</td>
<td>4/16 (25%)</td>
<td>.04</td>
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Patients were evaluated between day 30 and 40 after BMT for the presence of CMV-specific CD8' CTL and CD4' Th responses as described in Materials and Methods. Donor CMV serologies were determined by enzyme immunoassay (Whittaker Bioproducts, Walkersville, MD). Statistical analysis comparing the proportions of patients with recovery of CD8' CTL and CD4' Th responses in relation to donor CMV serology was done using Fisher's exact test.

placebo and the 4 patients who were not eligible for randomization. At this early time posttransplant, CD8' CTL responses had recovered in 8/22 patients receiving marrow from a CMV seropositive donor compared with 1/16 patients receiving marrow from a CMV seronegative donor (P = .07) (Table 3). CD4' Th responses had recovered in 14/22 recipients of marrow from a CMV seropositive donor compared with 4/16 recipients of marrow from a CMV seronegative donor (P = .04) (Table 3). Thus, donor CMV serology appears to be a major factor influencing the early detection of CMV-specific immune responses after BMT.

Influence of ganciclovir prophylaxis on CMV-specific T-cell recovery between days 40 and 90 after BMT. An effect of ganciclovir prophylaxis on CMV-specific T-cell reconstitution should be most discernible in patients without detectable responses at day 30 to 40. Thus, using identical culture conditions and target cells, CMV-specific T-cell responses were reevaluated between day 80 and 90 after BMT in the 29 surviving patients. Overall, at this later time, 10/16 (63%) placebo patients and 5/13 (39%) ganciclovir patients had measurable CD8' CMV-specific CTL responses with 12/16 (75%) placebo recipients and 9/13 (69%) ganciclovir recipients having CD4' CMV-specific Th responses. All patients that were positive for CTL and Th at the day 30 through 40 evaluation retained these responses at the day 90 evaluation and patients with CD8' CTL responses had preexisting or concurrent recovery of CD4' Th.

Twelve of the 15 placebo patients and 9 of the 11 ganciclovir recipients that were deficient in CD8' CTL at day 40 were alive and reevaluated at day 90. Six of the 12 placebo recipients, but only 1 of the 9 ganciclovir recipients had reconstituted CD8' CMV-specific CTL at reevaluation (Table 4). The patient in the ganciclovir group that showed recovery of CD8' CTL did not have ganciclovir therapy interrupted and did not excrete CMV on surveillance cultures. This patient had received marrow from a CMV seropositive donor and showed a positive CD4' CMV-specific Th response at the initial evaluation. Eight of the 11 placebo and 5 of the 7 ganciclovir recipients that were deficient in CD4' Th responses were alive and reevaluated at day 90. Five of the 8 placebo recipients and 1 of the 5 ganciclovir recipients reconstituted CMV-specific Th responses between the first and second evaluation (Table 4). The one patient with recovery of CD4' Th had ganciclovir discontinued at day 75 and was not evaluated until day 125, and thus, this recovery may have reflected a T-cell response to reactivation of CMV occurring in the interval off ganciclovir.

These results show a strong correlation between ganciclovir prophylaxis and failure to recover both CD8' CTL and CD4' Th CMV-specific T-cell responses between day 40 and 90 after BMT. Perhaps because of the small numbers of patients on this study, the difference between ganciclovir and placebo recipients in recovery of CD4' Th or CD8' CTL responses during the day 40 to 90 interval did not achieve statistical significance when each response was analyzed as an isolated variable (Table 4). However, if the total number of CMV-specific T-cell responses (ie, CD4' Th plus CD8' CTL) that recovered between day 40 and 90 in placebo patients is compared with the total number of T-cell responses recovering in ganciclovir recipients the differences between the two groups is significant. Eleven of 20 deficient CMV-specific T-cell responses recovered between the first and second evaluation in individuals receiving placebo compared with 2 of 14 deficient responses in those receiving ganciclovir (P = .04) (Table 4).

Influence of graft-versus-host disease on endogenous CMV-specific T-cell reconstitution. GVHD has previously been shown to be a risk factor for CMV disease, and by inference would be associated with delayed reconstitution of CMV-specific T-cell responses. We evaluated the effect of GVHD on reconstitution of CMV-specific immune re-

Table 4. Recovery of CMV-Specific CD8' CTL and CD4' Th Responses at Day 80 to 90 After BMT in Patients Deficient in These Responses at Day 40

<table>
<thead>
<tr>
<th>Recovery of a CMV-specific</th>
<th>Placebo</th>
<th>Ganciclovir</th>
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<tbody>
<tr>
<td>CD8' CTL response*</td>
<td>6/12</td>
<td>1/9</td>
</tr>
<tr>
<td>CD4' Th response†</td>
<td>5/8</td>
<td>1/5</td>
</tr>
<tr>
<td>No. of deficient CMV-specific T-cell responses recovering‡</td>
<td>11/20</td>
<td>2/14</td>
</tr>
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</table>

* The presence of a CD8' CMV-specific CTL response in PBMC at day 80 to 90 was evaluated in patients randomized to ganciclovir or placebo using the CTL generation assay described in Materials and Methods.
† The presence of a CD4' CMV-specific Th response in PBMC at day 80 to 90 was evaluated in patients randomized to placebo or ganciclovir using the lymphoproliferation assay described in Materials and Methods.
‡ The total number of deficient CMV-specific immune responses that recovered in ganciclovir recipients. The numerator is the number of CMV-specific T-cell responses (CD4' Th plus CD8' CTL) that recovered between day 40 and 90 and the denominator is the total number of T-cell responses that were deficient at day 40.
CMV-specific T-cell responses. Of the 7 placebo recipients recovery of CMV-specific T-cell responses was observed in statistically significant by day 40 and CMV-specific T-cell responses, 3 recovered these responses placebo recipients and with grade 0 to 1 GVHD and complete reconstitution of with 8 of 16 placebo recipients and 6 of 13 ganciclovir received placebo and 13 received ganciclovir. GVHD occurred in patients with grade 0 to 1 GVHD and complete recovery of CMV-specific T-cell immunity in patients receiving ganciclovir prophylaxis is caused by effective suppression of virus replication during the period of drug administration.

Table 5. Effect of GVHD Grade on Reconstitution of CMV-Specific CD8+ CTL and CD4+ Th Responses at Day 90

<table>
<thead>
<tr>
<th>Grade 0 to 1 GVHD</th>
<th>Grade 2 to 4 GVHD</th>
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</table>
| Recovery of CD8+ CTL | 10/14 | 5/15 | *P = .10*
| Recovery of CD4+ Th | 14/14 | 7/15 | *P = .01*
| Recovery of both CD8+ CTL and CD4+ Th | 10/14 | 5/15 | *P = .10*

CMV-specific T-cell responses were analyzed as described in Materials and Methods. GVHD was graded by standard criteria, and the maximum grade of GVHD developing during the first 90 days post-transplant was used for data analysis.

Responses in the 29 patients that survived to be studied at day 90. Fourteen patients had grade 0 to 1 GVHD and 15 had grade 2 to 4 GVHD. All 14 patients with grade 0 to 1 GVHD, but only 7 of 15 patients with grade 2 to 4 GVHD had recovered CD4+ CMV-specific Th responses by day 90 and this difference was significant (P = .01) (Table 5). Ten of the 14 patients with grade 0 to 1 GVHD and 5 of 15 patients with grade 2 to 4 GVHD recovered CD8+ CMV-specific CTL (P = .10) (Table 5). Thus, complete reconstitution of both CD8+ CTL and CD4+ Th was observed more frequently in patients with grade 0 to 1 GVHD (10/14), than in patients with grade 2 to 4 GVHD (5/15), although this was not statistically significant (P = .10).

Sixteen of the 29 patients evaluated through day 90 received placebo and 13 received ganciclovir. GVHD occurred with similar frequency and severity in both arms of the study with 8 of 16 placebo recipients and 6 of 13 ganciclovir recipients developing grade 0 to 1 GVHD. Seven of the 8 placebo recipients and 3 of the 6 ganciclovir recipients with grade 0 to 1 GVHD reconstituted both CD8+ and CD4+ CMV-specific T-cell responses. Of the 7 placebo recipients with grade 0 to 1 GVHD and complete reconstitution of CMV-specific T-cell responses, 3 recovered these responses by day 40 and 4 recovered the responses in the interval between day 40 and 90. All 3 of the ganciclovir recipients with grade 0 to 1 GVHD and complete recovery of CMV-specific T-cell responses showed recovery by day 40, and no recovery was observed in the day 40 to 90 interval in the other 3 patients. Of the 8 remaining placebo recipients and 7 ganciclovir recipients with grade 2 to 4 GVHD, complete recovery of CMV-specific T-cell responses was observed in 3 placebo and 2 ganciclovir recipients, respectively. Although these numbers are clearly too small for a meaningful statistical analysis, the failure of 3 ganciclovir patients with grade 0 to 1 GVHD to reconstitute CMV-specific T-cell immunity suggests that GVHD is not the sole factor explaining the failure of CMV-specific immune recovery in this group of patients.

Virologic monitoring of ganciclovir and placebo patients. The development of antigen-specific T-cell responses after BMT can reflect the transfer of memory T cells from the marrow donor, but in circumstances where these cells are transferred in small numbers or where the donor has not been primed to the respective antigen, in vivo stimulation is likely to be required for expansion of specific T-cell precursors. Thus, recovery of T-cell responses to CMV may require reactivation of virus in vivo and stimulation of CMV-specific T-cell precursors. The results of weekly cultures for CMV provide support for the hypothesis that the delay in reconstitution of CMV-specific T-cell responses in patients receiving ganciclovir may reflect a lack of viral antigen stimulation. Five of the six placebo patients with recovery of CD8+ CMV-specific CTL responses after day 40 had culture evidence from throat, blood, or urine of CMV reactivation, but none of the ganciclovir recipients had positive cultures. Thus, these results suggest that the delayed recovery of CMV-specific T-cell immunity in patients receiving ganciclovir prophylaxis is caused by effective suppression of virus replication during the period of drug administration.

Correlation of CMV-specific T-cell responses and CMV disease occurrence. CMV disease occurred in 8 of the 34 patients randomized to either ganciclovir or placebo and 3 of 4 nonrandomized patients. Seven of these 11 patients developed CMV interstitial pneumonia and 4 patients developed CMV enteritis as the initial manifestation of CMV disease. Two of the four patients with CMV enteritis subsequently developed CMV pneumonia. Of the 11 cases of CMV disease, 2 occurred in patients in the ganciclovir arm and both were pneumonia. These cases occurred at days 125 and 153 after BMT and in both patients ganciclovir had been discontinued before or on day 100. The median day of onset of CMV disease in the patients not receiving ganciclovir prophylaxis was day 48 (range 43 to 74), which is consistent with the median of day 56 observed in prior studies. None of the 11 patients developing CMV disease had CD8+ CMV-specific CTL detected in the peripheral blood in the assay before the development of CMV disease or when reevaluated with 2 days of the establishment of the diagnosis of CMV disease. However, 3 of these 11 patients had detectable CD4+ CMV-specific Th responses although the stimulation indices were low (mean 2.6, range 1.6 to 4.7). Sixteen of the 38 patients reconstituted CD8+ CMV-specific CTL responses during the course of this study, and none of these patients developed CMV disease subsequent to the endogenous recovery of CD8+ CTL. The association of a positive CD8+ CTL response and protection from CMV disease was highly significant (P = .005) and substantiates previous findings in a smaller study showing the correlation of deficient class I HLA-restricted CMV-specific CD8+ CTL responses with the occurrence of CMV disease. Despite the occurrence of CMV disease in a small number of patients with CD4+ Th responses, overall the reconstitution of lymphoproliferative responses to CMV was associated with protection from CMV disease (P = .01), consistent with the requirement for CD4+ Th for the in vivo generation of CD8+ CTL.

Specificity of CD8+ CMV-specific CTL responses developing in BMT recipients. Although CMV encodes a large number of proteins that are potential target antigens, the host CTL response effective in controlling persistent infection in seropositive individuals is specific for a small number of viral proteins. The dominant target antigens recognized are structural viral proteins and the majority of CTL clones iso-
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Many patients reactivated HSV when acyclovir was discon-
risk for CMV disease. This would permit ganciclovir therapy to be selectively utilized and minimize ganciclovir-related hematopoietic toxicity, which is observed in 30% of patients receiving ganciclovir prophylaxis and is associated with an increased risk of bacterial infections.13-31 The results of our study suggest that evaluating patients for recovery of CD8+ CMV-specific CTL responses would identify those patients that have reconstituted these responses and do not need ganciclovir prophylaxis. This approach would eliminate 25% of patients from consideration for prophylactic ganciclovir by day 30 to 40 after BMT. A similar evaluation of patients beyond day 100 may help guide the clinical use of ganciclovir late after BMT. Such an approach should reduce the toxicities incurred with long-term ganciclovir therapy while ensuring that immunocompromised patients still at risk of CMV disease are identified.

An alternative strategy to prevent CMV infection after allogeneic BMT is to reconstitute protective immune responses by the adoptive transfer to the BMT recipient of CD8+ CMV-specific T-cell clones derived from the BM donor and propagated by in vitro culture.32 In a previous study, we reported that this therapy was not associated with any toxicity and resulted in the selective and persistent reconstitution of CMV-specific CTL responses in all treated patients.10 The CD8+ CMV-specific CTL isolated from healthy CMV seropositive BM donors are predominantly specific for structural viral proteins processed and presented by infected cells without the requirement for viral gene expression.4 The epitopes recognized by CTL are conserved in genetically distinct clinical isolates of CMV including ganciclovir-resistant strains (S.R. Riddell, unpublished data, August 1992). Thus, adoptively transferred CTL may provide protection against the ganciclovir-resistant CMV strains that are increasingly identified in immunosuppressed hosts receiving ganciclovir.33-35 In this report, we have extended the observation that recovery of CD8+ CTL after BMT correlates with protection from CMV disease to show that the specificity of endogenously recovering CTL is predominantly directed at structural virion proteins. Thus, the nature of the protective responses that develop after BMT appear to be the same as those maintained in healthy seropositive individuals. This further affirms that adoptive immunotherapy with T-cell clones derived from the donor to reconstitute immunity in the recipient may be particularly useful in selected clinical circumstances where prolonged immunodeficiency is predicted and ganciclovir therapy is poorly tolerated.

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Recovery of HLA-restricted cytomegalovirus (CMV)-specific T-cell responses after allogeneic bone marrow transplant: correlation with CMV disease and effect of ganciclovir prophylaxis

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