Graft-versus-Host Disease Impairs Vaccine Responses through Decreased CD4+ and CD8+ T Cell Proliferation and Increased Perforin-Mediated CD8+ T Cell Apoptosis

Christian M. Capitini, Nicole M. Nasholm, Brynn B. Duncan, Martin Guimond and Terry J. Fry

*J Immunol* 2013; 190:1351-1359; Prepublished online 28 December 2012;
doi: 10.4049/jimmunol.1200391
http://www.jimmunol.org/content/190/3/1351

**Supplementary Material**
http://www.jimmunol.org/content/suppl/2013/01/04/jimmunol.1200391.DC1

**References**
This article cites 44 articles, 28 of which you can access for free at:
http://www.jimmunol.org/content/190/3/1351.full#ref-list-1

**Subscription**
Information about subscribing to *The Journal of Immunology* is online at:
http://jimmunol.org/subscription

**Permissions**
Submit copyright permission requests at:
http://www.aai.org/About/Publications/JI/copyright.html

**Email Alerts**
Receive free email-alerts when new articles cite this article. Sign up at:
http://jimmunol.org/alerts
Graft-versus-Host Disease Impairs Vaccine Responses through Decreased CD4+ and CD8+ T Cell Proliferation and Increased Perforin-Mediated CD8+ T Cell Apoptosis

Christian M. Capitini,*,# Nicole M. Nasholm,* Brynn B. Duncan,* Martin Guimond,‡ and Terry J. Fry*

Tumor-targeted vaccines represent a strategy to enhance the graft-versus-leukemia effect after allogeneic blood and marrow transplantation (BMT). We have previously shown that graft-versus-host disease (GVHD) can negatively impact quantitative responses to vaccines. Using a minor histocompatibility Ag–mismatched BMT (B6→B6 × C3H.LSW) followed by adoptive transfer of HY-specific T cells and HY-expressing dendritic cells, we assessed whether GVHD induced by donor lymphocyte infusion (DLI) affects the persistence, proliferation, and survival of vaccine-responding, nonalloantigen reactive T cells. Both CD8+ and CD4+ HY-specific T cells undergo less vaccine-driven proliferation in allogeneic recipients with GVHD. Although vaccine-responding CD8+ T cells show decreased IFN-γ and CD107a production, CD4+ T cells exhibit increased programmed death 1 and T cell Ig mucin-like domain 3 expression. In addition, the degree of apoptosis in vaccine-responding CD8+ T cells was higher in the presence of GVHD, but there was no difference in CD4+ T cell apoptosis. Using Fas ligand–deficient or TRAIL-deficient DLI had no impact on apoptosis of HY-specific T cells. However, perforin-deficient alloreactive DLI induced significantly less apoptosis of vaccine-responding CD8+ T cells and resulted in enhanced tumor protection. Thus, diminished vaccine responses during GVHD result from impaired proliferation of CD8+ and CD4+ T cells responding to vaccination, with an additional contribution from perforin-mediated CD8+ T cell apoptosis. These results provide important insights toward optimizing vaccine responses after allogeneic BMT.

The Journal of Immunology, 2013, 190: 1351–1359.

Allogeneic blood and marrow transplantation (alloBMT) is associated with prolonged lymphopenia that predisposes to infection and relapse. Because thymic function is limited early after alloBMT, mature T cells in the graft or provided as a donor lymphocyte infusion (DLI) contribute substantially to immune recovery but also induce graft-versus-host-disease (GVHD), which further impairs thymic function (1). Prior studies have documented that GVHD has direct deleterious effects on mature donor T cells transferred with the graft (2), because of shortened survival in the periphery (3, 4) and activation-induced cell death (5, 6). Furthermore, GVHD may indirectly constrain the expansion of mature T cells (2, 7). The result is that, despite the contribution of alloreactivity to preventing relapse, the detrimental effects of GVHD on immune recovery could undermine strategies to manipulate the antitumor response.

Observations made by other groups clearly demonstrated that diminished proliferation and increased apoptosis contributes to T cell dysfunction in both preclinical alloBMT models and during clinical alloBMT (3–5, 7–10). One of the limitations of prior studies that have examined the impact of alloreactivity on T cell populations expanding after alloBMT has been the difficulty to identify T cells with no cross-reactivity against minor histocompatibility Ags (mHAs) on the host. In addition, the contribution of a competing nonalloantigen stimulus, in the form of a vaccine, to T cells present in the setting of GVHD has not been explored in depth.

Vaccines have demonstrated efficacy in the autologous setting in expanding T cells specific for tumor-associated Ags (TAAs) and have the potential to enhance the graft-versus-leukemia (GVL) effect (11–18). We have previously demonstrated that even mild GVHD adversely impacts the magnitude of immune responses to a vaccine targeting Ags not expressed on normal host tissues (12) through an undefined mechanism. Although the deleterious impact of GVHD on T cell populations as a whole has been well established, few studies have carefully characterized the effect of the alloreactive environment on nonalloreactive T cells responding to a vaccine (18, 19). In this report, we studied the capacity for vaccine-responding T cells with known Ag specificity toward nonallogeneic Ags to proliferate and survive in the setting of GVHD after MHC-mismatched, mHA-mismatched alloBMT. We also explored the mechanism by which DLI-mediated GVHD increases apoptosis of nonalloreactive, adoptively transferred, vaccine-

Abbreviations used in this article: alloBMT, allogeneic blood and marrow transplantation; BMT, blood and marrow transplantation; DC, dendritic cell; DLI, donor lymphocyte infusion; FasL, Fas ligand; GVHD, graft-versus-host disease; GVL, graft-versus-leukemia; Ig, immunoglobulin; IL-2, interleukin-2; mHA, minor histocompatibility Ag; PD-1, programmed death 1; TAA, tumor-associated Ag; TCD, T cell-depleted; TCRαβ, TCR transgenic; TIM3, T cell Ig mucin-like domain 3.

Received for publication February 17, 2012. Accepted for publication December 3, 2012.

1Blood and Marrow Transplant Section, Pediatric Oncology Branch, Center for Cancer Research, National Cancer Institute, National Institutes of Health, Bethesda, MD 20892; 2Department of Pediatrics, University of Wisconsin Carbone Cancer Center, University of Wisconsin School of Medicine and Public Health, Madison, WI 53705; and 3University of Montreal, Maisonneuve-Rosemont Hospital, Montreal, Quebec, Canada H1T 2M1

The content of this publication does not necessarily reflect the views or policies of the Department of Health and Human Services, nor does mention of trade names, commercial products, or organizations imply endorsement by the U.S. Government.

Address correspondence and reprint requests to Dr. Christian M. Capitini, University of Wisconsin, 1111 Highland Avenue, WIMR 4137, Madison, WI 53705. E-mail address: ccapitini@pediatrics.wisc.edu

The online version of this article contains supplemental material.

The Journal of Immunology 2013, 190: 1351–1359.

www.jimmunol.org/cgi/doi/10.4049/jimmunol.1200391

The online version of this article contains supplemental material.

www.jimmunol.org/cgi/doi/10.4049/jimmunol.1200391

www.jimmunol.org/cgi/doi/10.4049/jimmunol.1200391
responder T cells by examining the contribution of three effector pathways: Fas ligand (Fasl), TRAIL, and perforin.

Materials and Methods

Mice

Congenic CD45.1+ C57BL/6 (H-2b) (B6) and CD45.2+ B6 mice were purchased from the National Cancer Institute animal production colony (Frederick, MD), and B6 Rag2−/−, B6 Fasl−/− (gld), B6 Prf1−/−, C3H. SW, and B6 × C3H.SW (all H-2b) (F1) mice were purchased from The Jackson Laboratories (Bar Harbor, ME). F1 mice underwent intraperitoneal (i.p.) injection of 104 U of polyinosinic-polycytidylic acid (Roche, Indianapolis, IN) to induce systemic tolerance. To study vaccine-induced proliferation and apoptosis of CD8+ and CD4+ T cells, we compared the quantity of Marilyn and Matahari cells with GVHD compared with syngeneic recipients. By gating CD4+ T cells with known specificity for the male HY Ag (Fig. 1A).

Flow cytometry

Spleens and lymph nodes were harvested and stained at 4°C for 20 min with 4μg/ml monoclonal antibodies (eBiosciences). For intracellular staining of IFN-γ, cells were fixed and permeabilized with an mAb mixture containing Vb1, Vb2, Vb3, Vb4, and CD45.2 mice were then cultured in a 24-well plate at a 1:1 ratio with splenocyte-derived DCs for 72 h. Wells were then harvested, counted, and analyzed by flow cytometry. Matahari cells were identified by Vb8.3 and CD45.2 expression.

Statistical analysis

Statistical tests were performed using GraphPad Prism version 4.0c for Macintosh (GraphPad Software, San Diego, CA). Significant differences when comparing two groups were determined by two-tailed Mann–Whitney U test. Kruskal–Wallis with Dunn’s multiple-comparison posttest was used to assess statistical differences between three or more groups. Log-rank analysis was done for survival experiments. A p value <0.05 was considered significant.

Results

GVHD decreases recovery of nonalloreactive, vaccine-responding T cells

Irradiated female mice were transplanted with TCD mHA-mismatched bone marrow (CD45.1+ B6→CD45.1+/CD45.2+ B6 × C3H.SW), followed by infusion of congenic CD45.1+ polyclonal donor T cells as a delayed DLI to induce GVHD. This platform was used to study vaccine-induced proliferation and apoptosis of CD8+ and CD4+ T cells with known specificity for the male HY Ag (Fig. 1A). Thymectomized recipients were chosen to mimic poor thymic function observed in humans early after alloBMT and to restrict T cell recovery to those contained in the adoptively transferred inocula. Because female donors and recipients were used, Ags causing GVHD could not contribute to the proliferation of vaccine-responding HY-specific T cells. In this model, donor chimerism is nearly 100% (Fig. 1B), and a delayed DLI given on day +14 induces weight loss in allogeneic recipients (Fig. 1C) without lethality. Also, as expected, the donor-derived DC vaccine does not exacerbate GVHD because HY is not expressed by the female recipients. Furthermore, HY-specific T cells do not undergo lymphopenia-induced proliferation (LIP) (25) (Fig. 1D). Thus, proliferation could be interpreted as being either vaccine driven or a nonspecific effect of the allogeneic environment.

On day +28, CD8+ TCR transgenic (TCRTg) T cells (Matahari, CD45.2+, Vb8.3+) specific for the immunodominant class I HY Ag (UTY) or CD4+ TCRtg T cells (Marilyn, CD45.2+, Vb6+) specific for the immunodominant class II HY Ag (DBY) were given in conjunction with a male DC vaccine. To examine the impact of the allogeneic environment on recovery of vaccine-responding T cells, we compared the quantity of Marilyn and Matahari cells in the spleens of unvaccinated and vaccinated allogeneic recipients with GVHD compared with syngeneic recipients. By gating on congenic markers and the associated TCR Vβ-β2 molecule, we were able to identify the vaccine-responding T cells (Fig. 2A).

There was no difference in recovery of CD43 Marilyn T cells between syngeneic and allogeneic recipients (Fig. 2C). There was an identical pattern with respect to CD83 Matahari T cells (Fig. 2D, E). These findings are also consistent with our prior observation of decreased HY-specific responses expanded from polyclonal T cells by HY vaccination (12). To exclude that the allogeneic environment did not change the trafficking pattern of HY-specific T cells.
to lymphoid organs, we also analyzed pooled lymph nodes and found similar results (Supplemental Fig. 1A–D).

**GVHD prevents proliferation of Ag-specific CD4+ and CD8+ T cells from DC vaccination to a nonalloantigen**

To determine the mechanism of diminished recovery of vaccine-responding T cells observed during GVHD, we measured proliferation of CFSE-labeled Marilyn and Matahari T cells in separate experiments. Neither Marilyn nor Matahari T cells proliferated in the absence of a vaccine (Fig. 3A–D), confirming earlier reports that LIP is insufficient to drive T cell division and demonstrating that the allogeneic environment does not induce proliferation. In syngeneic BMT recipients, Marilyn T cells (Fig. 3A, 3C) and Matahari T cells showed robust proliferation after vaccination (Fig. 3E). As expected with a single vaccine, proliferation was synchronized, resulting in two distinct peaks, representing Ag-responding and nonresponding cells, rather than the typical multiple divisions noted in polyclonal T cells during LIP (Fig. 1D) (26). However, GVHD significantly impaired proliferation of both Marilyn and Matahari vaccine-responding cells (Fig. 3A, 3C, 3E).

To assess additional functional characteristics of vaccine-responding T cells, we analyzed cytokine production and lytic potential of Matahari T cells after vaccination of allogeneic and syngeneic recipients. As shown in Fig. 3F, the absolute number of Matahari cells producing IFN-γ in response to HY DC vaccination was significantly reduced in the setting of GVHD, as was the absolute number CD107a+ Matahari T cells (Fig. 3G). Thus, in addition to reduced proliferation and total HY-specific T cell recovery, GVHD also affected the number of functional vaccine-responding CD8+ T cells.

To begin to address the mechanism for the reduced proliferation of Marilyn T cells in response to vaccination, we assessed the expression of markers of T cell dysfunction in both allogeneic and syngeneic recipients. As shown in Fig. 3H, both PD-1 receptor and TIM3 was more highly expressed on Marilyn T cells in allogeneic recipients as compared with syngeneic recipients. Interestingly,
although the expression of these markers was increased by DC vaccination, there was higher PD-1 and TIM3 on Marilyn T cells in allogeneic recipients in the absence of HY vaccination. Because HY is not an allogeneic Ag in this system, these results suggest a nonspecific “bystander effect” induced by GVHD that does not require the presence of cognate Ag.

GVHD increases apoptosis of CD8+, but not CD4+, T cells responding to vaccination

We next tested whether increased apoptosis also contributed to diminished recovery of vaccine-responding T cells. Because there was a large proportion of undivided (CFSE+) T cells present in mice with GVHD, we were particularly interested in assessing whether these cells were undergoing apoptosis and thus unable to proliferate to the vaccine. Whereas there were equivalent numbers of undivided, CFSE+ Annexin V+ Marilyn T cells after both syngeneic and alloBMT (Fig. 4A, 4B) with or without a vaccine, there was a significant increase in apoptosis of vaccine-responding Matahari T cells in the lymph nodes of alloBMT recipients (Fig. 4D). Interestingly, no differences in the percentage CFSE+ Annexin V+ T cells were observed in the spleen (data not shown). Although a reduction in CD4 and CD8 vaccine-induced proliferation was seen in both spleen and lymph nodes of mice with GVHD, there was no increase in CD4 apoptosis in splenic T cells. We hypothesized that, in this model, simultaneous presentation of alloantigens to alloreactive T cells and HY Ags to HY-specific T cells may partially explain the increased bystander apoptosis observed in HY-specific T cells. To test this, we performed in vitro coculture experiments with Matahari T cells and male DCs in the presence or absence of alloantigen presentation. Indeed, as shown in Fig. 4E, the recovery of Matahari T cells was reduced when cultured with allogeneic T cells plus DCs presenting both HY and alloantigens, with an increased fraction of Annexin V+ Matahari T cells noted.

Vaccine-induced apoptosis in the setting of GVHD can be reversed through disruption of the perforin pathway resulting in restoration of vaccine-mediated tumor protection

Because the TCRTg T cells in our model do not recognize an alloantigen and do not undergo expansion in either syngeneic or

---

**FIGURE 2.** GVHD decreases recovery of vaccine-responding T cells. Mice were transplanted per Fig. 1A. (A) A sample flow cytometry gating schema on (top panels) a F1 recipient transplanted with syngeneic CD45.1+CD45.2+ F1 bone marrow and DLI, followed by CD45.1+CD45.2+ Matahari splenocyte infusion, as well as (bottom panels) a F1 recipient transplanted with allogeneic CD45.1+CD45.2+ B6 bone marrow and DLI, followed by CD45.1+CD45.2+ Matahari splenocyte infusion. The CD45.2+ Vβ8.3+ fraction in both BMTs represents the HY-reactive T cells from the Matahari infusion in the recipient spleen. (B) Absolute numbers of CD4+Vβ6+CD45.2+ Marilyn T cells in the host spleen were enumerated by flow cytometry 3, 5, and 7 d (days +31, 33, and 35 post-BMT) after adoptive transfer without concurrent male DC vaccination, or (C) with male DC vaccination, 4–9 mice/group, pooled from 3 independent experiments. (D) Absolute numbers of CD8+Vβ8.3+CD45.2+ Matahari T cells in the host spleen were enumerated by flow cytometry 3, 5, and 7 d (days +31, 33, and 35 post-BMT) after adoptive transfer without concurrent male DC vaccination, or (E) with male DC vaccination, 3–9 mice/group. *p < 0.05, pooled from three independent experiments.
allogeneic recipients without a vaccine, alloantigen could not directly mediate apoptosis. Rather, we hypothesized that alloreactive T cells present in the DLI were mediating bystander apoptosis of vaccine-responding CD8+ T cells, as has been reported for polyclonal T cells of unknown specificity in the absence of a vaccine (5). To determine which molecules were regulating bystander apoptosis, we infused DLIs deficient in specific cytolytic pathways that could be potentially used by the DLI to induce apoptosis in the vaccine-responding CD8+ T cells (Fig. 5A). Prior work has implicated both Fas-FasL (3, 5, 27–37) and perforin (29, 33–35, 37–39) in alloantigen-reactive T cell apoptosis during GVHD. In our model, DLI deficient in FasL or TRAIL did not result in reduced apoptosis of vaccine-responding CD8+ T cells. However, infusing DLI deficient in perforin resulted in a modest, but significantly reduced, percentage of undivided, apoptotic Matahari in spleen (Fig. 5B) and 50% decrease in the lymph nodes (Fig. 5C) of alloBMT recipients.

In our model, DLI deficient in FasL or TRAIL did not result in reduced apoptosis of vaccine-responding CD8+ T cells. However, infusing DLI deficient in perforin resulted in a modest, but significantly reduced, percentage of undivided, apoptotic Matahari in spleen (Fig. 5B) and 50% decrease in the lymph nodes (Fig. 5C) of alloBMT recipients.

Discussion

Tumor-targeted vaccines are a promising approach to direct immune responses after alloBMT. Indeed, a number of preclinical studies have demonstrated the efficacy of such a strategy (11–18), and clinical trials using vaccines after alloBMT are under way. However, preventative and therapeutic interventions for GVHD, as well as GVHD itself, are globally immunosuppressive. Furthermore, the impact of the allogeneic environment on T cells expanding in response to a vaccine has not been well characterized. We have previously demonstrated that sublethal GVHD is immunosuppressive, leading to decreased vaccine responses to TAAs (12). We confirm the reduction in vaccine responses after alloBMT in this study using CD4+ and CD8+ T cells with known specificity for a nonalloantigen. The ability to carefully track the behavior of these T cells in the allogeneic recipients allowed us to establish that this reduction in vaccine responses is due to diminished proliferation and, for CD8+ T cells, increased bystander apoptosis mediated, at least in part, by perforin.

Previous studies have used proliferative rate to distinguish between alloreactive and nonalloreactive T cells (8) but did not definitively identify nonalloreactive T cells based on known TCR specificity. Using this approach, cytokines have been shown to enhance global T cell reconstitution, with enhanced graft versus
tumor responses demonstrated in some of these studies (40–43). However, the impact on Ag-specific T reconstitution was not analyzed. A few studies have specifically assessed the impact of alloreactive T cells on cognate Ag-driven expansion of T cells with known specificity for a nonalloantigen (18, 19). Jenq et al. (19) performed TCD alloBMT to demonstrate that recombinant keratinocyte growth factor could enhance thymic output, improve DNA vaccine responses, and enhance tumor protection, but did not specifically address the question whether GVHD affects vaccine responses. Manzo et al. (18) used both an HY-alloreactivity model and mHA-disparate transplant model to demonstrate that early vaccine responses against nonalloantigens are preserved at 1 week, but persistence beyond 2 wk is impaired in the setting of GVHD, consistent with our earlier observations (12). However, the specific mechanism by which vaccine-responding T cells are lost was not analyzed. We specifically found that GVHD impairs CD4+ and CD8+ T cell responses to a vaccine, in part, from diminished Ag-induced proliferation. These data support recent clinical data demonstrating that CD8+ T cells recognizing TAAs from acute myeloid leukemia fail to proliferate in an alloBMT environment (9). Interestingly, these authors suggest that one explanation may be that GVHD induces a state of replicative senescence, whereby the T cells are in a nonproliferative and apoptosis-resistant state from chronic stimulation.

Although the studies presented in this article allow definite discrimination of vaccine-responding nonalloreactive T cells made possible through the use of murine transplant models and TCRTg T cells, they must be interpreted with caution in terms of relevance to clinical alloBMT in humans. However, given the complexity of the allogeneic milieu and difficulty in developing in vitro systems using human cells or xenogeneic models, murine models represent an important tool in understanding the immunobiology of alloBMT. Although we did not use immunosuppressive medications, such as calcineurin inhibitors typically used after alloBMT...
in humans, posttransplant interventions would likely be most effective after these medications are discontinued. Furthermore, because of graft manipulation, alloBMTs without or with limited use of immunosuppressive medications are being used with increasing frequency. Thus, we believe these results present important, and potentially clinically relevant, insights into the use of tumor-directed vaccine approaches after alloBMT.

Clinical studies have shown increased apoptosis of T cells after alloBMT (3, 4, 6, 10), but as with proliferation, these studies are not able to distinguish between T cells that recognized alloantigen and T cells with no reactivity against alloantigen. In a murine study by Alpdogan et al. (8), rapidly proliferating T cells that acquire CD44 high expression with presumed specificity for alloantigen demonstrated increased apoptosis. In our study, we show that known nonalloreactive CD8+ T cells, in particular, nondividing T cells with vaccine specificity, undergo increased apoptosis in the allogeneic environment. Interestingly, we did not see increased apoptosis of these T cells in absence of cognate Ag stimulation. However, the combination of cognate Ag plus the allogeneic environment resulted in marked apoptosis of CD8+ T cells. In contrast, our data indicate that vaccine-specific CD4+ T cell apoptosis does not contribute to impaired responses during GVHD. Although our results are consistent with a report that polyclonal CD8+ T cells from recipients of HLA-matched sibling alloBMT appear more sensitive to apoptosis than CD4+ T cells (3), they contrast with another report concluding the opposite in recipients of HLA-matched unrelated donors (4). In neither of these clinical studies and in prior murine studies was the specificity of the T cells analyzed for apoptosis known, and could have contained alloreactive T cells, nonalloreactive T cells, or both. Nonetheless, the studies presented in this article, where T cells with known specificity for nonalloantigen were evaluated, demonstrate that the impact of GVHD on CD8+ T cell apoptosis does not require recognition of alloantigen by the vaccine-responding cells. Our
results also suggest that administering a vaccine with prosurvival cytokine such as IL-7 or IL-15 may decrease CD8+ T cell apoptosis further (40, 41), particularly of nonalloreactive T cells, such as those used in our alloBMT model.

A multitude of studies have demonstrated that FasL, perforin, and TRAIL can all contribute to the pathophisiology of GVHD (3, 5, 27–39). In the majority of these studies, these pathways were implicated in the effector mechanisms by which alloreactive T cells mediate tissue injury. In our model, we were specifically interested in the role these molecules play in the deletion of nonalloreactive T cells responding to a vaccine. Alpdogan et al. (8) demonstrated that apoptosis of rapidly proliferating cells resulted in impaired lymphocyte recovery via a mechanism that does not require Fas or TRAIL on donor bone marrow. Notably, these studies examined effects on polyclonal T cell populations. Brochu et al. (5) demonstrated that alloreactive T cells can cause bystander apoptosis of infused polyclonal nonalloreactive T cells via Fas-FasL. In this study, we used T cells with known Ag specificity to assess the mechanism of apoptosis in vaccine-responding T cells induced by the allogeneic environment. Surprisingly, this appears to be mediated, at least in part, by perforin rather than FasL. The difference in the pathway involved may reflect either vaccine-induced changes in T cell susceptibility to Fas or to trafficking. Indeed, the most marked decline in apoptosis with perforin-deficient DLI was noted in the lymph nodes rather than the spleen, but led to enhanced tumor protection. Consistent with our results, human regulatory T cells have been shown to respond to a vaccine. Alpdogan et al. (8) demonstrated that apoptosis of rapidly proliferating cells resulted in impaired lymphocyte recovery via a mechanism that does not require Fas or TRAIL on donor bone marrow. Notably, these studies examined effects on polyclonal T cell populations.

Acknowledgments

We thank Crystal Mackall, Rimas Orentas, Paul Sondel, and Manish Patankar for critically reviewing data and providing helpful feedback.

Disclosures

The authors have no financial conflicts of interest.

References

Supplemental Figure 1

A) CD4

No vaccine

<table>
<thead>
<tr>
<th>Days post Marilyn DLI</th>
<th>Allogeneic</th>
<th>Syngeneic</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

B) CD4

Vaccine

<table>
<thead>
<tr>
<th>Days post Marilyn DLI</th>
<th>Allogeneic</th>
<th>Syngeneic</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

C) CD8

<table>
<thead>
<tr>
<th>Days after Matahari DLI</th>
<th>Allogeneic</th>
<th>Syngeneic</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

D) CD8

<table>
<thead>
<tr>
<th>Days after Matahari DLI</th>
<th>Allogeneic</th>
<th>Syngeneic</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Supplemental Figure 1: GVHD decreases recovery of vaccine-responding T cells in the lymph nodes:

Mice were transplanted per Figure 1A. (A) Absolute numbers of CD4⁺Vβ6⁻CD45.2⁺ Marilyn T cells in the host lymph nodes were enumerated by flow cytometry 3, 5 and 7 days (days +31, 33 and 35 post-BMT) after adoptive transfer without concurrent male DC vaccination, or (B) with male DC vaccination, 4-9 mice/group, pooled from three independent experiments. (C) Absolute numbers of CD8⁻Vβ8.3⁺CD45.2⁺ Matahari T cells in the host lymph nodes were enumerated by flow cytometry 3, 5 and 7 days (days +31, 33 and 35 post-BMT) after adoptive transfer without concurrent male DC vaccination, or (D) with male DC vaccination, 3-9 mice/group. # = p = 0.05, * = p < 0.05, pooled from three independent experiments.