Clinical Study
Longitudinal Analysis of Tetanus- and Influenza-Specific IgG Antibodies in Myeloma Patients

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Received 8 November 2011; Revised 25 December 2011; Accepted 28 December 2011

1. Introduction

Multiple myeloma (MM) is a disease arising from a malignant plasma cell clone proliferating in the bone marrow (BM) [1]. On the one hand, the growing tumor mass leads to a reduction of normal hematopoiesis, and, secondly, myeloma cells create a cytokine/chemokine microenvironment favoring the malignant phenotype while suppressing local and systemic immunity [2]. Both factors contribute to the profound immune dysregulation present in myeloma patients [3]. MM patients evidence phenotypic and functional defects of humoral as well as cellular immunity. Particularly B-cell responses are altered to a state of functional hypogammaglobulinemia, leading to an increased risk for opportunistic infections in MM patients [3]. As a consequence of the impaired protective immunity against bacteria and viruses, infections represent a major cause of death in MM patients [4]. The administration of intravenous immunoglobulin (IVIG) has been used to temporarily restore antibody-mediated immunity, in particular after high-dose...
chemotherapy [5]. However, it is unknown to what extent and for how long the passively transferred humoral immunity compensates the severe disease- and therapy-related immunosuppression in myeloma patients.

As MM itself is dependent on the suppression and dysregulation of the adaptive immune response, the development of different modes of immunotherapy seems an attractive option for improving treatment of myeloma patients. Allogeneic stem cell transplantation is one of the most promising ways to restore the ability of the immune system to recognize and destroy MM cells [6]. The transfer of a healthy, donor-derived immune system, which is not tolerant to the malignant plasma cell clone, is currently the only potentially curative approach for MM patients [6]. The immunological graft-versus-myeloma effect (GvM) is powerful, but it comes along with a significant risk of developing a graft-versus-host reaction (GvHD), which represents a potentially deadly threat often requiring strong prophylactic (and sometimes therapeutic) immunosuppression [6, 7]. Optimized strategies are needed to determine exactly how much immunosuppression is needed to dampen harmful alloimmune reactions while still allowing for clinically required graft-versus-myeloma effects [7].

In order to improve our understanding of the therapy- and disease-related defects in the humoral immunity of myeloma patients, antibody responses need to be assessed repeatedly during the course of the disease. Memory immune responses induced by routine vaccinations or natural exposure, like the ones directed against influenza virus (FLU) and tetanus toxoid (TT), can serve as markers for the general immune competence of the patient at a given time point [8, 9]. Surprisingly, data on the longitudinal behavior of immune responses to such common antigens are scarce and have not been systematically addressed in MM patients [10, 11], in particular not after alloSCT. Here, we have performed the largest longitudinal analysis of FLU- and TT-specific antibody responses in MM patients to evaluate the consequences of the malignancy itself as well as of different modes of therapy on humoral immunity.

2. Material and Methods

2.1. Patients. Patients were admitted for diagnostic purposes and/or treatment to the University Medical Center Hamburg-Eppendorf. Repeated blood samples were obtained during routine diagnostic procedures, and all participants provided informed consent prior to sample collection. A total of 1094 peripheral blood (PB) plasma samples were collected from 194 consecutive MM patients. In addition, 100 PB sera were obtained from healthy donors. Samples were collected as previously described [12, 13]. Patients were included between December 2004 and February 2008. All patients were diagnosed and treated for MM. None of the patients had received new agents such as bortezomib, lenalidomide, or thalidomide. AutoSCT was generally performed twice in a tandem setting. Induction treatment for alloSCT routinely comprised 140 mg/m² melphalan, 150 mg/m² fludarabine, and 30–60 mg anti-thymocyte globulin per kg. Peripheral hematopoietic grafts were used for transplantation and cyclosporine A (until day 180) and mycophenolate mofetil (until day 54) were used as GVHD prophylaxis. No patient received consolidation or maintenance treatment. Only single patients received sporadically received donor lymphocyte infusions. All patients received i.v. immunoglobulins on day 1, 7, 14, 21, 28, 54, and 86 after alloSCT. Booster vaccines were applied one year after alloSCT for FLU and TT, respectively.

This study was conducted in accordance with the declaration of Helsinki. The protocol had received approval by the local ethics committee (decision number OB-038/06).

2.2. Proteins and Peptides. Recombinant influenza nucleoprotein (FLU) produced in E. coli was obtained from Imgenex (San Diego, CA, USA) and tetanus toxoid (TT) was provided by Chiron Behring (Marburg, Germany). Control protein for FLU and TT antibody detection was GST expressed in E. coli (Cell Systems, St. Katharinen, Germany).

2.3. Enzyme-Linked Immunosorbent Assay (ELISA). ELISA was performed as previously described [13]. For all samples, the GST background value was subtracted [13]. For all samples, the GST background value was subtracted [13]. For all samples, the GST background value was subtracted [13]. For all samples, the GST background value was subtracted [13].

2.4. Statistical Analysis. Statistical analyses were performed using GraphPad software. To avoid bias by repeated sampling, samples were stratified according to the time frame during which they were sampled (e.g., before alloSCT or 3 months after alloSCT) and a mean value was calculated for all samples of a given patient collected within a given time frame. In a second step, these values were used to determine the mean for the respective group of patients (i.e., all myeloma patients per time frame) as suggested by Bland and Altman [14, 15]. The Mann-Whitney U test was used to calculate differences between different patient cohorts. Analysis of covariance was used to assess correlations between FLU- and TT-specific antibodies. Correlations between clinicopathological variables and FLU- or TT-specific antibodies were determined by Pearson’s χ² test. All tests were performed as univariate analyses. Differences were regarded significant if P < 0.05.

3. Results

3.1. Myeloma Patients Evidence Reduced Levels of FLU- and TT-Specific IgG Antibodies Compared to Healthy Controls. Over a time course of 4 years, a total of 194 consecutive MM patients were included into this study, and from the respective patients, 1094 PB samples were collected. A mean number of 5.4 (range 1–47) serum samples were collected per patient during a median follow-up period of 11.4 months (range 1–39 months). Most patients were included at advanced stages of the disease (mainly stage II and III according to the Salmon and Durie classification), and all but 10 patients had received chemotherapy, autologous stem cell transplantation (autoSCT), or alloSCT, respectively, as maximum therapy prior to study inclusion (see Table I for patient characteristics).
Table 1: Patient characteristics. Data are shown for all patients. LC: light chain, HC: heavy chain. * indicates missing information for some patients.

| Parameter       | Total |
|-----------------|-------|
| Sex             |       |
| Male            | 115   |
| Female          | 75    |
| Age             |       |
| > 60            | 69    |
| ≤ 60            | 121   |
| Karyotype       |       |
| Normal          | 83    |
| Complex         | 15    |
| del13q14        | 46    |
| del17p13        | 12    |
| t(4;14)         | 9     |
| Not tested      | 25    |
| LC isotype      |       |
| Light lambda    | 62    |
| Light kappa     | 100   |
| HC isotype*     |       |
| IgG             | 167   |
| IgA             | 18    |
| Maximum treatment|     |
| Untreated       | 10    |
| Chemotherapy    | 81    |
| autoSCT         | 30    |
| alloSCT         | 74    |
| Stage*,#,#      |       |
| I               | 32    |
| II              | 52    |
| III             | 95    |

*One patient was found to bear a 13q14 and a 17p13 deletion.
#Stage according to the Salmon and Durie classification.

When we compared levels of IgG antibodies directed against FLU or TT between myeloma patients and healthy donors (N = 100), we found both types of humoral responses to be significantly reduced in the patients (Figure 1(a)). To address if the FLU- and TT-specific antibodies reflected the general humoral capacity of the given group of subjects to a comparable extent, we performed correlational analyses. Indeed, we observed that levels of FLU- and TT-specific IgG antibodies correlated positively and highly significantly in patients as well as those in the group of donors (Figure 1(b)). This finding further indicated that a state of general immunosuppression was present in the patients, irrespective of the nature of the given antigen. It is important to note, however, that myeloma patients were compared to unselected, anonymized blood donors and that we, therefore, cannot rule out that differences observed were partly related to confounding factors, that is, the median age of each group of subjects.

3.2. FLU and TT Specific Antibodies Show a Transient Increase Followed by a Long-Lasting Suppression after AlloSCT. Since both alloSCT and autoSCT are known to have significantly impact on the immune capacity of the patient, we asked how IgG antibody responses against FLU and TT are influenced by each type of transplantation. Only such patients were included in this analysis who had either received autoSCT or alloSCT as maximum therapy. When we monitored levels of FLU- and TT-specific antibodies before and after autoSCT, we did not find any major changes during the follow-up period when compared to pretransplant values (Figure 2). In contrast, both FLU and TT antibodies significantly increased during the first three months after alloSCT to a level comparable to healthy donors. Thereafter, humoral responses declined significantly and remained suppressed for 3 and more than 5 years in the case of FLU- and TT-specific antibodies, respectively.

To analyze the influence of alloSCT on humoral immunity against FLU and TT in a more detailed manner, we selected a cohort of patients of whom we had been able to obtain samples during the last 6 months before alloSCT and the first 6 months after alloSCT. Comparing levels of FLU- and TT-specific antibodies for this homogenous collective at both time points, we confirmed our observation of a significant increase following alloSCT (Figure 3(a)). In contrast, no significant change was found when we compared the same time points in a group of patients who had received autoSCT (Figure 3(a)). Next we compared samples of the same patients, collected at time points equal 6 months or less after alloSCT with samples collected more than 6 months after alloSCT. We were able to demonstrate that 6 months represent an important cutoff with regard to the humoral immunity of MM patients after alloSCT (Figure 3(b)). In contrast no difference in FLU- or TT-specific antibodies was found when autoSCT patients were monitored over the same period of time (data not shown).

3.3. Levels of FLU and TT Antibodies Correlate Negatively with Markers of Poor Prognosis in MM. As a next step, we correlated FLU and TT antibody levels with a large variety of clinicopathological measures (Table 2). For FLU-specific antibodies, the only statistically significant association was found for concentrations of total IgG in IgG myeloma with lower IgG concentration being associated with elevated anti-FLU antibody levels (Table 2). On the other hand, higher levels of TT-specific antibodies were significantly associated with younger age (<60 years) and normal serum calcium and albumin as well as normal IgG concentrations in IgG myeloma. Overall, these associations suggest that general immunoreactivity decreases with progressing disease and worsening clinical status of the patient.

4. Discussion

Analyzing the largest cohort of MM patients to date for the presence of FLU- and TT-specific antibodies, we found myeloma patients to evidence significantly reduced levels of antibodies against both antigens. MM patients are known
to be deficient in polyclonal immunoglobulins [16]. Upon vaccination MM patients show a delayed increase in IgM, a quicker shift to IgG and lower titers of antibodies against the target antigen [17]. The general B-cell dysfunction in myeloma patients results in antibody titers below protective levels, rendering MM patients more susceptible to infections despite vaccination [3, 18]. Levels of FLU- and TT-specific antibodies have been investigated in small cohorts of MM patients, mostly revealing lower antibody titers in MM than in healthy controls [18–21]. In our large longitudinal study, we were able to confirm these results and we believe that these reduced levels of antibodies against two selected targets indeed reflect the negative impact of the malignancy and previous therapies on the humoral (and probably also cellular) immunity in myeloma patients. This idea would also be supported by our observation of a negative correlation between TT- and/or FLU-specific antibody levels and markers of a poor prognosis in MM such as paraprotein levels and concentrations of serum calcium and albumin as well as the patient’s age.

In addition to the aforementioned parameters we detected a strong influence of alloSCT on the levels of TT- and FLU-specific IgG antibodies in myeloma patients. We observed elevated antibody levels during the first 6 months after alloSCT followed by a suppression of humoral immunity for up to 5 years and more. Treatments such as chemotherapy, autoSCT, and alloSCT have previously been shown to significantly influence the immune system of cancer patients [9, 10, 22, 23]. In MM, small studies have suggested alloSCT to impair the humoral immune response, but little is known about the time course of this suppression, and data on ideal time points for vaccination are controversial.

**Figure 1:** Comparison of levels of FLU- and TT-specific antibodies in MM patients compared to healthy donors. (a) Mean values for FLU- and TT-specific specific antibodies for HD (n = 100) and MM patients (N = 190). OD 405 nm of the background control GST was subtracted for each sample. Asterisks indicate significant differences (***P < 0.001) between groups. (b) Correlational analysis of FLU- and TT-specific antibodies in HD (N = 100) and MM patients (N = 190).
Figure 2: Time course of FLU- and TT-specific antibodies in MM patients undergoing alloSCT. Samples harvested in the frame of allo- and autoSCT were sorted according to time after transplantation. Only those patients were included into this analysis who had alloSCT or autoSCT, as maximum therapy. For the samples collected in the frame of alloSCT the group numbers of samples per time point were as follows: 30, 24, 24, 18, 19, 45, 33, and 20. For the samples collected in the frame of alloSCT, the group numbers of samples per time point were as follows: 25, 21, 10, 10, 4, 18, 2, and 2. Asterisks indicate significant differences when compared to the time point “3 months” after SCT (**P < 0.01 and ***P < 0.001).

In our current study, we were able to demonstrate that, as in other diseases requiring alloSCT, immunity to FLU and TT decreases over time following transplantation, most likely as a surrogate marker of prolonged immunosuppression [25]. On the other hand, we also found a transient increase of FLU and TT antibodies in the first 6 months following alloSCT. While there are a number of possible explanations for this increase, we believe that it is most likely caused by intravenous substitution with polyclonal intravenous immunoglobulins (IVIGs) commonly performed at our center during the first months post transplantation [26]. This hypothesis would be consistent with previous studies describing large amounts of both FLU- and TT-specific antibodies as parts of IVIG preparations [27].

Another interesting observation we have made in our current analysis is that, following the initial amplification of humoral immune responses against TT and NP, antibody levels were suppressed for at least 3 years in the case of FLU-specific immunity while TT-specific antibodies remained below early post-alloSCT (<6 months) levels for the whole remaining observation period. There are four possible explanations for the discrepancies in the behavior of both antibody specificities. First, based on the fact that FLU-specific immunity is often acquired spontaneously while TT-specific humoral responses are always generated by vaccination, that repeated natural exposures to influenza antigen may have boosted the antibody response [8, 18]. On the other hand, TT-specific vaccination may have less stringently been performed than FLU-specific vaccination because, in contrast to influenza infections, tetanus infections are not a leading cause of mortality in MM patients. This hypothesis is least likely to fit, since at our institutions, TT antibodies are routinely monitored and low titers lead to repeated booster vaccinations. Third, Ek et al. have previously reported that in
Figure 3: Time-dependent impact of alloSCT on FLU- and TT-specific antibodies in selected patients. (a) Comparison of FLU and TT antibodies 6 months before and 6 months after alloSCT and autoSCT. For 21 alloSCT patients and for 14 autoSCT patients, samples had been collected for both of these time points. Differences were significant with $P < 0.001$ for FLU-antibodies before and after alloSCT and with $P < 0.0001$ for TT antibodies before and after alloSCT. No significant differences were found between FLU and TT antibody concentrations before and after autoSCT. (b) Comparison of FLU and TT antibodies collected less than 6 months after alloSCT and more than 6 months after alloSCT. Samples had been collected from 20 alloSCT patients at both time points. Differences in antibody titers were significant in the case of anti-FLU ($P < 0.01$) and anti-TT antibodies ($P < 0.0001$).
| Parameter                      | Stratification | N   | Mean (FLU) | Mean (TT) |
|-------------------------------|----------------|-----|------------|-----------|
| Gender                        | men            | 115 | 1,042      | 1,202     |
|                               | women          | 75  | 0,918      | 1,133     |
| Age                           | ≤ 60 years     | 122 | 0,969      | 1,253*    |
|                               | > 60 years     | 67  | 1,034      | 1,023*    |
| Hemoglobin                    | low            | 157 | 1,022      | 1,181     |
|                               | normal         | 30  | 0,859      | 1,087     |
| Albumin                       | < 35 g/l       | 27  | 0,877      | 0,699*    |
|                               | ≥ 35 g/l       | 158 | 1,015      | 1,247*    |
| LDH                           | ≤ 225 U/l      | 137 | 1,007      | 1,156     |
|                               | > 225 U/l      | 49  | 0,972      | 1,194     |
| Calcium                       | ≤ 2,63 mmol/l  | 182 | 0,995      | 1,145*    |
|                               | > 2,63 mmol/l  | 2   | 1,040      | 2,470*    |
| Creatinin                     | ≤ 1,3 mg/dL    | 146 | 0,990      | 1,123     |
|                               | > 1,3 mg/dL    | 37  | 1,035      | 1,355     |
| IgG (for IgG myeloma)         | ≤ 16 g/l       | 44  | 1,018      | 1,248*    |
|                               | > 16 g/l       | 41  | 0,746      | 0,874*    |
| IgG (for IgA myeloma)         | ≤ 16 g/l       | 39  | 0,994      | 1,103     |
|                               | > 16 g/l       | 4   | 0,883      | 0,870     |
| IgA (for IgA myeloma)         | ≤ 4 g/l        | 17  | 0,986      | 1,151     |
|                               | > 4 g/l        | 26  | 0,982      | 1,034     |
| Kappa-light chains            | ≤ 3,7 g/l      | 14  | 1,116      | 1,557     |
|                               | > 3,7 g/l      | 0   | —          | —         |
| Lambda-light chain            | ≤ 2 g/l        | 12  | 1,164      | 1,007     |
|                               | > 2 g/l        | 1   | 0,210      | 0,030     |
| Deletion 13q14                | positive       | 46  | 0,900      | 1,014     |
|                               | negative       | 117 | 1,038      | 1,218     |
| Deletion 17p13                | positive       | 13  | 1,058      | 1,350     |
|                               | negative       | 150 | 0,989      | 1,142     |
| Translocation t (4; 14)       | positive       | 9   | 0,933      | 0,793     |
|                               | negative       | 153 | 0,998      | 1,178     |
| β2-Microglobulin              | ≤ 3 mg/l       | 60  | 0,970      | 1,200     |
|                               | > 3 mg/l       | 32  | 0,807      | 0,942     |
| GvHD                          | positive       | 42  | 0,885      | 0,965     |
|                               | negative       | 21  | 0,893      | 1,172     |
| Plasma cells in BM            | ≤ 10%          | 68  | 0,978      | 1,241     |
|                               | > 10%          | 37  | 0,949      | 1,006     |

*indicates a statistically significant result (P < 0.05); if not otherwise specified, differences between groups are not significant.

Leukemia patients levels of TT- but not *Haemophilus influenzae*-specific antibodies correlated negatively with disease recurrence and were less protective in these immunosuppressed patients [8] indicating that the extent of treatment-induced humoral immunosuppression might indeed depend on the type of the given antigen [8]. Accordingly, it has previously been described that antiviral antibody responses were more stable with a half-life of up to 50 years compared to 10 years for antibacterial responses, that is, against TT [28]. We, therefore, believe that the latter concept is most likely to explain the different time-frames until recovery of TT- and NP-specific antibodies after alloSCT.
Overall, our current findings support the concept that MM is associated with a profound disease- and therapy-related immunosuppression which is compensated for a few months after alloSCT by the application of intravenous immunoglobulin. This and the fundamental differences regarding the recovery of anti-FLU and anti-TT antibody titers during the following years need to be taken into account for optimizing strategies for IVIG application and active immunization after alloSCT.

Acknowledgments

This work was supported by grants from the Eppendorfer Krebs- und Leukämiehilfe, the Deutsche José Carreras Leukämie-Stiftung, and from the Cancer Research Institute (to D. Atanackovic).

References

[1] A. Palumbo and K. Anderson, “Multiple myeloma,” The New England Journal of Medicine, vol. 364, no. 11, pp. 1046–1060, 2011.
[2] Y. Cao, T. Luetkens, S. Kobold et al., “The cytokine/chemokine pattern in the bone marrow environment of multiple myeloma patients,” Experimental Hematology, vol. 38, no. 10, pp. 860–867, 2010.
[3] N. C. Munshi, “Immunoregulatory mechanisms in multiple myeloma,” Hematology/Oncology Clinics of North America, vol. 11, no. 1, pp. 51–69, 1997.
[4] D. Trono and Y. Kapanci, “Causes of death in cases of lymphoma, myeloma and Hodgkin disease. Study of 218 cases,” Schweiz Med Wochenschr, vol. 113, no. 19, pp. 701–708, 1983.
[5] P. Raanani, A. Gafter-Gvili, M. Paul, I. Ben-Bassat, L. Leibovici, and O. Shipilberg, “Immunoglobulin prophylaxis in hematological malignancies and hematopoietic stem cell transplantation,” Cochrane Database of Systematic Reviews, no. 4, p. CD006501, 2008.
[6] H. Lokhorst, H. Einsele, D. Vesole et al., “International myeloma working group consensus statement regarding the current status of allogeneic stem-cell transplantation for multiple myeloma,” Journal of Clinical Oncology, vol. 28, no. 29, pp. 4521–4530, 2010.
[7] N. Kroger. “Unrelated stem cell transplantation for patients with multiple myeloma,” Current Opinion in Hematology, vol. 17, no. 6, pp. 538–543, 2010.
[8] T. Ek, L. Mellander, M. Hahn-Zoric, and J. Abrahamsson, “Avidity of TcTu and Hib antibodies after childhood acute lymphoblastic leukaemia—implications for vaccination strategies,” Acta Paediatrica, vol. 95, no. 6, pp. 701–706, 2006.
[9] C. M. van Tilburg, E. A. M. Sanders, M. M. Rovers, T. F. W. Wolfs, and M. B. Bierings, “Loss of antibodies and response to (re-)vaccination in children after treatment for acute lymphocytic leukemia: a systematic review,” Leukemia, vol. 20, no. 10, pp. 1717–1722, 2006.
[10] T. Norday, A. Husebekk, I. S. Aaberge et al., “Humoral immunity to viral and bacterial antigens in lymphoma patients 4–10 years after high-dose therapy with ABMT. Serological responses to revaccinations according to EBMT guidelines,” Bone Marrow Transplantation, vol. 28, no. 7, pp. 681–687, 2001.
[11] N. C. Issa, F. M. Marty, L. S. Gagne et al., “Sero protective titers against 2009 H1N1 Influenza A Virus after Vaccination in Allogeneic Hematopoietic Stem Cell Transplantation Recipients,” Biology of Blood and Marrow Transplantation, 2010.
[12] A. D. Atanackovic, T. Luetkens, Y. Hildebrandt et al., “Longitudinal analysis and prognostic effect of cancer-tests antigen expression in multiple myeloma,” Clinical Cancer Research, vol. 15, no. 4, pp. 1343–1352, 2009.
[13] S. Kobold, S. Tams, T. Luetkens et al., “Patients with multiple myeloma develop SOX2-specific autoantibodies after allogeneic stem cell transplantation,” Clinical and Developmental Immunology, vol. 2011, Article ID 302145, 10 pages, 2011.
[14] J. M. Bland and D. G. Altman, “Calculating correlation coefficients with repeated observations: part 2—correlation between subjects,” British Medical Journal, vol. 310, no. 6980, p. 633, 1995.
[15] J. M. Bland and D. G. Altman, “Calculating correlation coefficients with repeated observations: part I—correlation within subjects,” British Medical Journal, vol. 310, no. 6977, p. 446, 1995.
[16] L. M. Pilarski, B. A. Ruether, and M. J. Mant, “Abnormal function of B lymphocytes from peripheral blood of multiple myeloma patients. Lack of correlation between the number of cells potentially able to secrete immunoglobulin M and serum immunoglobulin M levels,” Journal of Clinical Investigation, vol. 75, no. 6, pp. 2024–2029, 1985.
[17] J. Harris, R. Alexanian, E. Hersh, and P. Migliore, “Immune function in multiple myeloma: impaired responsiveness to keyhole limpet hemocyanin,” Canadian Medical Association Journal, vol. 104, no. 5, pp. 389–393, 1971.
[18] J. D. Robertson, K. Nagesh, S. N. Jowitt et al., “Immunogenicity of vaccination against influenza, Streptococcus pneumoniae and Haemophilus influenzae type B in patients with multiple myeloma,” British Journal of Cancer, vol. 82, no. 7, pp. 1261–1265, 2000.
[19] B. Maecker, K. S. Anderson, M. S. Von Bergwelt-Baldon et al., “Viral antigen-specific CD8+ T-cell responses are impaired in multiple myeloma,” British Journal of Haematology, vol. 121, no. 6, pp. 842–848, 2003.
[20] H. S. Birgens, F. Espersen, and J. B. Hertz, “Antibody response to pneumococcal vaccination in patients with myelomatosis,” Scandinavian Journal of Haematology, vol. 30, no. 4, pp. 324–330, 1983.
[21] D. Raperelli, L. Sticchi, O. Racchi, R. Mangerini, A. M. Ferraris, and G. F. Gaetani, “Influenza vaccine in chronic lymphoproliferative disorders and multiple myeloma,” European Journal of Haematology, vol. 70, no. 4, pp. 225–230, 2003.
[22] Y. Ilan, A. Nagler, E. Zeira, R. Adler, S. Slavin, and D. Shouval, “Maintenance of immune memory to the hepatitis B envelope protein following adoptive transfer of immunity in bone marrow transplant recipients,” Bone Marrow Transplantation, vol. 26, no. 6, pp. 633–638, 2000.
[23] P. Garland, H. de Lavallade, T. Sekine et al., “Humoral and Cellular Immunity to Primary H1N1 Infection in Patients with Hematologic Malignancies following Stem Cell Transplantation,” Biology of Blood and Marrow Transplantation, 2010.
[24] B. Mohty, M. Bel, M. Vukicevic et al., “Graft-versus-host disease is the major determinant of humoral responses to the AS03-adjuvanted influenza A/09/H1N1 vaccine in allogeneic hematopoietic stem cell transplant recipients,” Haematologica, vol. 96, no. 6, pp. 896–904, 2011.
[25] E. J. A. Gerritsen, M. J. D. Van Tol, M. B. Van ’t Veer et al., “Clonal dysregulation of the antibody response to tetanus-toxoid after bone marrow transplantation,” Blood, vol. 84, no. 12, pp. 4374–4382, 1994.

[26] P. Raanani, A. Gafter-Gvili, M. Paul, I. Ben-Bassat, L. Leibo-ovich, and O. Shpilberg, “Immunoglobulin prophylaxis in hematopoietic stem cell transplantation: systematic review and meta-analysis,” Journal of Clinical Oncology, vol. 27, no. 5, pp. 770–781, 2009.

[27] A. Vrdoljak, A. Tresc, B. Benko, and M. Simic, “A microassay for measurement of Fc function of human immunoglobulin preparations by using tetanus toxoid as antigen,” Biologicals, vol. 32, no. 2, pp. 78–83, 2004.

[28] I. J. Amanna, N. E. Carlson, and M. K. Slifka, “Duration of humoral immunity to common viral and vaccine antigens,” New England Journal of Medicine, vol. 357, no. 19, pp. 1903–1915, 2007.