Serial serum protein electrophoreses were performed on 60 patients undergoing allogeneic and syngeneic bone marrow transplantation (BMT). More than 50% of patients (31 of 60) developed transient oligoclonal and monoclonal gammopathies that appeared an average of 84 days posttransplantation (range 27 to 336 days) and persisted an average of 175 days (range 14 to 652 days). Immunofixation analysis revealed 82% of the M components to be of the immunoglobulin G (IgG) type and 18% to be IgM; 56% were k and 44% were \( \lambda \). A strong correlation between development of graft versus host disease (GVHD) and appearance of M components was observed (73% incidence in GVHD patients vs 27% in non-GVHD patients, \( P < .0003 \)). Two of the three syngeneic graft recipients also developed monoclonal gammopathies. Evidence of oligoclonal circulating B-cell populations was found in 68% of patients posttransplantation by flow cytometric B-cell excess assay. No correlation of recovery of particular B- or T-lymphocyte subsets and development of M components was seen. The development of transient oligoclonal and monoclonal gammopathies after transplantation may be a ubiquitous finding reflecting recapitulation of early B-cell ontogeny.

**MATERIALS AND METHODS**

**Patient selection.** Sixty patients undergoing allogeneic (57) and syngeneic (3) BMT at the Brigham and Women's Hospital and The Children's Hospital between 1976 and 1986 were selected for study. There were 37 males and 23 females aged 1 month to 40 years. The mean age was 18 years. Pretransplantation diagnoses included aplastic anemia (16), acute myelogenous leukemia (14), acute lymphatic leukemia (10), chronic myelocytic leukemia (8), Wiskott Aldrich syndrome (4), severe combined immunodeficiency syndrome (SCIDS) (3), as well as myelofibrosis, Diamond Blackfan syndrome, neuroblastoma, osteopetrosis, and paroxysmal nocturnal hemoglobinuria (1 each). Forty-eight patients received HLA/MLC fully matched allografts, nine received grafts from histoincompatible donors, and three received syngeneic grafts. Eighteen of the 60 allografts were T-cell depleted ex vivo either by anti-Leu-1 monoclonal antibody (MoAb) and complement or anti-T12 MoAb plus complement.

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6 years. Normal levels for patients aged more than 6 years are 600% to 1,500 mg/dL for IgG, 50% to 200 mg/dL for IgM, and 60% to 290 mg/dL for IgA. These analyses were obtained weekly while patients were hospitalized (1 to 2 months posttransplantation) and monthly thereafter. A minimum of 15 studies was available for each patient. All marrow donors also had a single analysis before donation of marrow.

Monoclonal gammapathies. Clinical correlates. Fifty-two percent (31 of 60) of patients studied developed transient oligoclonal gammapathies after BMT, which appeared 84 days posttransplantation on the average (range 27 to 336) and persisted 175 days on the average (range 14 to 652). A representative analysis is shown in Fig 1. A minimum of three bands was visible in all patients, but a major single M component could be defined in 16 cases, and in six instances two M components were identified. Of the 28 M components identified, only IgG and IgM gammapathies were noted, occurring in 82% and 18% of cases, respectively. Of the six clearly identified biclonal M components, in two instances both IgG and IgM M components occurred simultaneously. In the 18 instances in which light chain type was identified, k and λ light chains occurred with approximately equal frequency (56% v 44%). No BM donor had evidence of oligoclonal or monoclonal M components.

There was no association of patient age, sex, diagnosis, major histocompatibility complex (MHC) compatibility, or type of GVHD prophylaxis (T-cell depletion v four dose methotrexate) with development of M components as assessed by chi-square analysis (Table 1). Monoclonal gammapathies were observed in 2 of the 3 patients who received syngeneic grafts. These two patients, including one reported previously, had a skin rash clinically and pathologically consistent with GVHD but did not develop intestinal or hepatic signs of this disorder.25,26 The two clinical correlates for development of monoclonal and oligoclonal immunoglobulin production included an initial positive skin test with mononuclear component.

There were two clinical correlates for development of monoclonal and oligoclonal immunoglobulin production. First, a strong correlation was detected between development of GVHD and appearance of posttransplantation M components. Of the 33 patients with acute or chronic GVHD, 73% (24 of 33) had transient gammapathies, whereas M compo-

![Fig 1. Representative serum protein electrophoresis and immunofixation electrophoresis. Left: Agarose electrophoresis pattern with oligoclonal banding (open arrows). Right: Immunofixation electrophoresis. Several M components are identified as IgG k and IgG λ bands (solid arrows).](image-url)
ments were noted in only 27% of patients without GVHD (9 of 33) \((P = .0003)\) by chi-square analysis with Yates correction. Patients in whom de novo chronic GVHD developed, (chronic GVHD not preceded by acute GVHD), had the same high incidence of M components as the group who had acute or acute plus chronic GVHD. Of the 12 patients with de novo chronic GVHD, 67% (8 of 12) had M components. Of the patients with M components, 21 had acute GVHD (7 with grade I, 6 with grade II, 7 with grade III, and 1 with grade IV) and 11 had chronic GVHD. The presence of GVHD did not affect timing or duration of the gammopathies.

A correlation was also noted between the type of conditioning regimen that patients received and development of posttransplantation M components. Specifically, patients receiving “marrow ablative” regimens (defined as conditioning that included either TBI or busulfan) had a higher incidence of M components (63%) than those receiving “nonablative” regimens (26%) \((P = .01)\). There was no correlation of GVHD with conditioning regimen in this study; therefore, as was expected, conditioning regimen and GVHD as compared in a multivariate analysis were independent predictive variables for development of oligoclonal and monoclonal banding on serum electrophoresis.

Two patients in the group of 60 developed posttransplantation lymphoproliferative disease; one patient had an M component posttransplantation that was of the same heavy and light chain class as that of his lymphoma, and the other had no monoclonal gammopathy. Both patients received T-cell-depleted HLA-mismatched allografts. The former developed GVHD posttransplantation that required further immunosuppressive therapy (including MoAbs), and the latter was maintained on cyclosporine prophylaxis posttransplantation.

Monoclonal gammopathies. Laboratory correlates. Blood lymphocyte phenotyping was performed on all transplanted patients. Data were analyzed at a date as close to M component appearance as possible. No correlation was evident between the presence of M components and total lymphocyte count or between absolute number or percentage of the following lymphocyte subsets: CD3, CD3\(^+\)CD4, CD3\(^+\)CD8, CD16, CD20, CD5, and CD20\(^+\)CD5\(^+\). No correlation was observed with the CD4/CD8 ratio. Development of M components did, however, relate strongly to quantitative immunoglobulin class levels after transplantation. Those patients without gammopathies demonstrated consistent absolute hypogammaglobulinemia as compared with those with M components. Immunoglobulin levels were compared between the M-component and non-M-component groups at the time of M component appearance and adjusted for age. In the latter group, immunoglobulin levels were obtained at as close to day 84 (average time to M component development) as possible. Of the 31 patients with oligoclonal or monoclonal gammopathies, seven (23%) were hypogammaglobulinemic, whereas 20 of 29 (69%) of patients in whom no M component was demonstrated were hypogammaglobulinemic \((P < .0011)\) by one-sided chi-squared analysis. Analysis of mean immunoglobulin levels in the two groups demonstrated the same phenomenon. Although all immunoglobulin classes were diminished in the non-M component group, this difference was particularly apparent for IgG (mean 494 vs 763 mg/dL; \(P = .04\)) by univariate analysis of variance.

Oligoclonal B cells demonstrated by B-cell clonal excess assay. Having shown a high frequency of apparent oligoclonal or monoclonal B-cell proliferation after BMT as reflected in secreted immunoglobulin, we determined whether these patients had circulating monoclonal or oligoclonal B-cell populations posttransplantation. B-cell clonal excess was analyzed in 16 patients (eight in the M-component group and eight in the non–M-component group). A clonal population was detected in approximately two thirds of patients tested, with equal frequency in the M-component and non–M-component groups (70% vs 67%).

DISCUSSION

Transient monoclonal gammopathies after irradiation and marrow reconstitution have been described in animal models. Only scattered reports and two patient series, however, describe the presence of monoclonal gammopathies after human marrow grafting. In the studies involving larger numbers of patients, the incidence of M components was reported to be between 42% and 90%. Vossen et al studied immunodeficiency in 43 children after allogeneic BMT for a variety of disorders. More than 90% demonstrated "homogeneous" immunoglobulins that appeared between 1 and 10 months posttransplantation and persisted for up to 3 to 4 years. The latter were mainly of the IgG and IgM classes, and the six cases examined expressed \(\kappa\) and \(\lambda\) light chain with equal frequency. Hammarstrom et al reported a lesser incidence of monoclonal gammopathies, approximately 42%, and noted a predominance of \(\lambda\) proteins. Our results confirm the common occurrence of M components posttransplantation and agree with the former study in which the two light chain types were found with equal frequency.

What causes monoclonal gammopathy after BMT? Most investigators speculate that the M components represent normal recapitulation of B-cell ontogeny or that they result from a malfunctioning T-cell system and a disturbance of T-B cell cooperation. Support exists for both explanations. Indeed, animal evidence suggests that this phenomenon is in part related to deficient T-cell function in the early posttransplantation period as infusion of additional T cells leads to a reduced incidence of M components in irradiated, reconstituted mice. However, because M components appear transiently when immunoglobulin levels are otherwise normal, and because they occur not only in patients with GVHD but also in patients receiving syngeneic and autologous transplants (Mitus AJ, Stein R, Smith BR, Alper CA, Antin JH: manuscript in preparation), we hypothesize that this phenomenon represents a normal, perhaps ubiquitous element of early B-cell ontogeny. If this is a relatively frequent occurrence after transplantation, how is the clinical association with GVHD explained? Immunologic dysfunction is accentuated in GVHD, further perturbing B-cell and T-cell function and interaction. Thus, occurrence of GVHD...
may render the normal phenomenon of oligoclonal banding more easily detectable.

M components may be associated with malignancies, particularly B-cell lymphoproliferative disorders. However, M components that appear postransplantation are different from those observed in neoplastic B-cell diseases. In chronic lymphocytic leukemia (CLL), hypogammaglobulinemia and perhaps monoclonal gammopathies (which occur in approximately 5% to 10% of cases) appear to result from primary B-cell dysfunction because addition of normal T cells in vitro does not improve immunoglobulin synthesis. An abnormal population of B lymphocytes marked by the CD5 antigen is probably responsible for production of the paraprotein when present in CLL and is phenotypically similar to an unusual population of B lymphocytes found postransplantation. However, unlike CLL, in which these cells are monoclonal, in the few cases that have been studied postransplantation the CD5+ B lymphocytes are polyclonal. In addition, we found no association between CD5+ B lymphocytes and the appearance of monoclonal gammopathies in our patients. Thus, the appearance of M components postransplantation probably does not reflect a B-cell neoplastic process. Likewise, development of postransplantation oligoclonal or monoclonal gammopathy does not appear to herald the later evolution to lymphoproliferative disease. Of the two patients who developed postransplantation lymphoma, only one demonstrated monoclonal gammopathy. In addition, other risk factors may have precipitated this complication in these patients, including use of HLA/MLC-mismatched donors and postransplantation immunosuppression. We cannot interpret the role of Epstein-Barr viral infection in this phenomenon because virtually all patients were antibody positive pretransplantation.

Hematopoietic reconstitution of the BM postransplantation may occur from a restricted number of clones. Immune reconstitution probably occurs in a clonal or oligoclonal manner as well, and the oligoclonal banding detected may represent, as suggested by Radl, “unequal development of several rapidly differentiated clones of immunoglobulin-producing cells.”

The donor versus recipient origin of the monoclonal protein found postransplantation remains uncertain. Although most evidence indicates a conversion of blood-borne cells and serum immunoglobulins to donor type by day 100 in most postransplant recipients, other studies have shown chimeric lymphocyte populations 6 months or more after transplantation. Therefore, the M components noted in our patients may be of host rather than of donor origin. That M components occurred more frequently in patients who received ablative conditioning regimens in this study suggests that at least some are donor derived; mixed chimerism is less common in patients receiving such preparative conditioning. Previous studies attempting to examine the donor-versus-host origin of M components by using Gm typing proved unsuccessful.

Evidence for monoclonal and oligoclonal B-cell proliferation within the first year after BMT can be found in most BMT recipients. Although this occurs most frequently in patients with GVHD, it does not appear to be associated with any long-term adverse consequences of transplantation.

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Monoclonal and oligoclonal gammopathy after bone marrow transplantation

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