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SCIENCE IN SOCIETY

How to Provide the Needed Protection from COVID-19 to Patients with Hematologic Malignancies

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Summary: Patients with hematologic malignancies are particularly vulnerable to COVID-19 infections, and upon a pooled data analysis of 24 publications, there is evidence that they have suboptimal antibody responses to COVID-19 vaccination and boosters. To provide them the needed additional protection from COVID-19, it is imperative to achieve a 100% full immunization rate in health care workers and adult caretakers, and to foster research to test higher doses and repeated rounds of COVID-19 vaccines and the use of passive immune prophylaxis and therapy.

Severe COVID-19 and death from COVID-19 have become preventable conditions in areas of the world with sufficient supply of highly active COVID-19 vaccines. However, this is not true for everyone, as many patients with hematologic malignancies have impaired responses to the COVID-19 vaccinations and require extra attention to protect them from COVID-19 (1, 2). These patients have an increased risk of complications and death from COVID-19 infection due to both their diagnosis frequently altering the function of B and T lymphocytes important for protection from the virus, and also by frequently receiving therapies that further damage lymphocytes, such as chemotherapy, corticosteroids, anti-CD20 antibodies, anti-CD38 antibodies, BTK inhibitors, stem cell transplantation, and chimeric antigen receptor (CAR) T-cell therapies. These factors have resulted in patients with hematologic malignancies being particularly vulnerable to COVID-19, making it imperative to provide them as much additional protection as possible once the COVID-19 vaccines first became available (3).

We reviewed the literature to gather information on the seroconversion rates in patients with hematologic malignancies after receiving a COVID-19 vaccine. We selected 18 series that provided anti–SARS-CoV-2 spike protein IgG seroconversion rates after full COVID-19 vaccination detailed by hematologic malignancy diagnosis, with at least 20 patients per group (Fig. 1; Supplementary Table S1; refs. 2, 4–19). The literature review also included six additional series that are not included in Fig. 1: three due to sampling of serum antibodies before achieving full vaccination as evidenced by lower seroconversions in the healthy control group compared with the rest of the series (20, 21) and three that did not provide breakdown of the data according to different histologic diagnoses (22, 23). There are a lot of variables that were not uniform in these series. For example, the type of COVID-19 vaccine and the timing of antibody analysis related to receiving the vaccine administration varied, with most analyzing samples obtained at 1 or 3 months after the full vaccination. In series that reported samples obtained at different time points, we report on the latest one. Important variables related to the hematologic malignancy, including being on active therapy, the type of therapy, being on watchful waiting before therapy, or having completed therapy, varied among the series and diagnoses. As a comparison, we provide the rates of seroconversion of healthy subjects from the series that included concomitant testing, which in some cases were age-matched controls (4, 6, 10, 12, 13, 15, 17, 19, 24). The combined healthy subject group adds to 729 individuals, with seroconversion rates between 98% and 100% (Fig. 1; Supplementary Table S1), suggesting that these series adequately tested for anti–SARS-CoV-2 spike protein seroconversion at the time when healthy subjects would have responded to the vaccine.

Despite the important caveats resulting from the variability in these series, there are general trends in the data. Patients with chronic lymphocytic leukemia (CLL) have a particularly low rate of seroconversion after COVID-19 vaccination, ranging from 39% to 71% in the reported series (2, 5–9). A similarly low rate of seroconversion is evident in series reporting on patients with non-Hodgkin lymphoma (NHL), ranging from 42% to 75% (2, 4, 8, 13, 14, 16–19, 24). One series reported on patients with Waldenstrom macroglobulinemia (WM) with a 74% seroconversion rate (2). These results of low seropositivity in some series while higher in others are likely to

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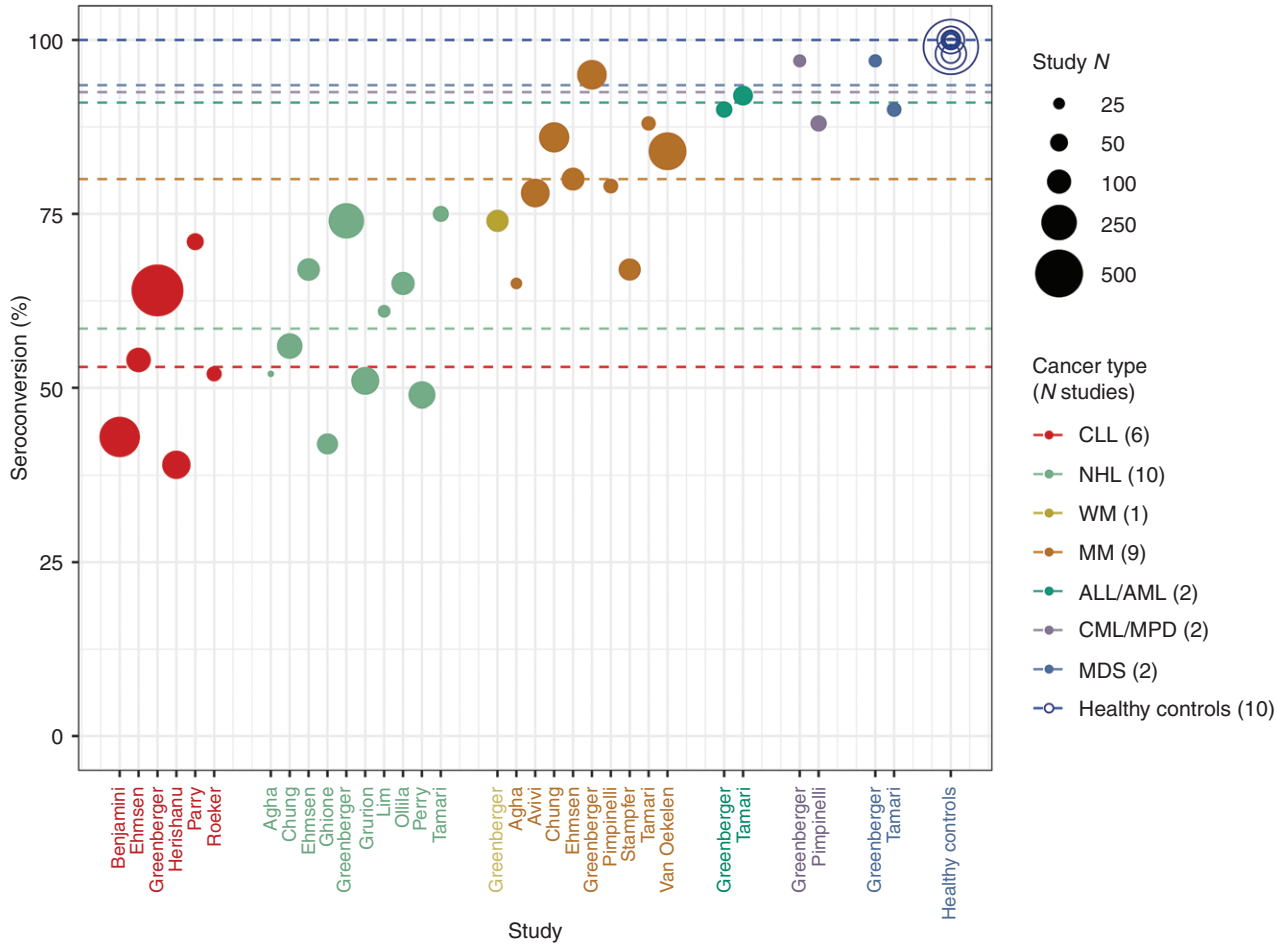

Figure 1. Rates of anti-SARS-CoV-2 spike protein IgG antibody seroconversion of patients with different histologies of hematologic malignancies compared with healthy subjects. The size of the round symbol is proportional to the number of subjects in each group. The healthy subject group is an overlay of the concurrent control groups from nine of the series. ALL/AML, acute lymphoblastic leukemia/acute myeloid leukemia; CLL, chronic lymphoblastic leukemia; CML/MPD, chronic myelogenous leukemia/myeloproliferative diseases; MDS, myelodysplastic syndromes; MM, multiple myeloma; NHL, non-Hodgkin lymphoma; WM, Waldenstrom macroglobulinemia.

be related to the treatments that the patients were receiving at the time of analysis and in particular the time since receiving therapy for the hematologic malignancy (13, 25). For example, patients with NHL recently treated with anti-CD20 were less likely to develop serologic response to a COVID-19 vaccine, with the rate of seropositivity in one series being 3% in patients vaccinated within 45 days from the last anti-CD20 administration, increasing to 80% in patients vaccinated over 1 year after stopping this therapy (18). Patients with NHL and CLL on BTK inhibitors also have a lower seropositivity after COVID-19 vaccination—in one series from 40% for patients on this targeted therapy to 73% for patients with the same diagnosis but being monitored for their disease without active therapy at the time of COVID-19 vaccination (23).

Patients with multiple myeloma were reported to have a seroconversion rate between 65% and 95% (2, 4, 8, 10, 12–15). Variability in these series may be related to patient's age, level of hypogammaglobulinemia, number of lines of therapy for myeloma, and in particular being on treatment with an anti-CD38 antibody, anti-BCMA therapy, or corticosteroid therapy, all of which were significant factors resulting in lower seroconversion rates in the different series (8, 10, 12, 13, 15). Rates of COVID-19 vaccination response were close to healthy subjects in patients with acute leukemia, chronic myelogenous leukemia (CML), and myelodysplastic syndromes (MDS; refs. 2, 4, 10). This may reflect the enrollment being skewed to patients who had been previously successfully treated for acute leukemia and low enrollment of patients on active chemotherapy, and the use of non–B-cell toxic therapies for the treatment of patients with CML, MDS, and acute myeloid leukemia.

Experience with similar low seroconversion rates in patients with hematologic malignancies when receiving vaccinations for other viral infections, in particular when on certain therapies (26), has led to the testing of higher doses of the vaccine, different formulations, and repeated rounds of immunization (27, 28). During the COVID-19 pandemic, some patients without seroconversion after receiving the full initial vaccination have received subsequent immunizations (sometimes referred to as boosters, but may not be the adequate term for persons who did not respond to the first set of vaccination). Initial data from a prospective registry

from The Leukemia & Lymphoma Society provide evidence that a third vaccine administration resulted in seroconversion in 21 of 38 patients (55%) who had not seroconverted with the initial round of immunization (29). In this report, most patients who were receiving anti-CD20 therapy or who had completed this therapy within the past 6 months, as well as patients on BTK inhibitors, failed to seroconvert even with the third COVID-19 vaccine administration. In another report, an additional dose of BNT162b2 also increased the anti-spike antibody levels above the predicted protective threshold in 48% of recipients of allogeneic hematopoietic stem cell transplants (30). Overall, even with a third vaccination, approximately half of the patients with hematologic malignancies who did not have seroconversion continue to have no antibody response to the COVID-19 vaccine.

Not all COVID-19 vaccine antibody responses are neutralizing antibodies to the SARS-CoV-2. virus. The quantitation of anti–SARS-CoV-2 spike protein IgG antibodies may not correctly measure protection to the virus and in particular to the Delta variant, which is the current prevalent variant in the United States. Data from patients with hematologic malignancies who had undergone CAR T-cell therapy or stem cell transplantation in the past demonstrated that higher spike antibody titers were associated with higher neutralization activity to the SARS-CoV-2 virus, with the 3-month levels of virus-neutralizing antibodies being lower than to the spike protein (77% compared with 87%; ref. 4). Similarly, in another series, levels of neutralizing antibodies to the SARS-CoV-2 virus at 3 months from COVID-19 vaccination were only 26% in patients with hematologic malignancies compared with 93% in concurrent healthy donors, and both were lower than the anti–SARS-CoV-2 spike protein quantitation, which was 89% overall for patients with hematologic malignancies (pooling data from patients with different leukemias, lymphomas, and myeloma) and 100% for the concurrent healthy controls (13). Neutralizing antibody levels were lowest for patients with CLL, frequently those on therapy with anti-CD20 or BTK inhibitors, and highest in patients with multiple myeloma, the majority of whom were on lenalidomide maintenance therapy, which parallels the levels of anti-spike antibody levels but with lower frequency (13). Therefore, the detection of anti–SARS-CoV-2 spike seroconversion rates overestimates the presence of neutralizing antibodies to the virus, raising concerns that patients with hematologic malignancies are at higher risk than what the commercial antibody tests suggest.

COVID-19 vaccination can provide benefit by inducing both antibody and T-cell responses to the SARS-CoV-2 virus. Because antibody responses are easier to measure with multiple commercial assays, it is logical that the field has focused on reporting serologic responses to the vaccination. Reliably detecting T-cell responses after COVID-19 vaccination is done in research settings, with a lot less information on the frequency of T-cell responses and their clinical significance. Patients with hematologic malignancies who survived the SARS-CoV-2 infection despite having low antibody levels were shown to have robust $CD8^+$ cytotoxic T-cell responses to the virus (31). There were still lower levels of $CD4^+$ T helper responses in these patients, which raises concerns about the ability of patients with hematologic malignancies to mount an adequate memory response to the virus after infection or vaccination. Studies in mouse models of SARS-CoV-2 demonstrate that both humoral and cellular adaptive immunity contribute to viral clearance in the setting of primary infection. Furthermore, convalescent mice or mice that receive mRNA vaccination are protected from both homologous infection and infection with a SARS-CoV-2 variant. In these mouse models, protection was largely mediated by antibody response and not T-cell immunity (32). Studies of antibody and T-cell responses to COVID-19 vaccination in patients with hematologic malignancies provide evidence that low antibody and T-cell responses are frequently associated (8), but in some cases, patients with low anti–SARS-CoV-2 spike protein antibody response had high T-cell responses to SARS-CoV-2 T-cell epitopes. Therefore, despite the known importance of T-cell responses to the virus, it seems correct to continue to analyze the serologic response to COVID-19 vaccination following anti–SARS-CoV-2 spike IgG antibodies as a main measure of protective immunity to the virus. However, it is acknowledged that further research is needed for the development of robust assays for T-cell responses to the virus that can be applied to larger series of patients and to define which levels of anti-spike antibodies convey protection to COVID-19.

The combined information makes it clear that patients with hematologic malignancies, in particular if they are on therapy with anti-CD20, anti-CD38, anti-BCMA, BTK inhibitors, JAK inhibitors, BCL2 inhibitors, chemotherapy, or corticosteroids, may not achieve sufficient levels of neutralizing antibodies to SARS-CoV-2 even after repeated administration of COVID-19 vaccines (2, 8, 13, 29). Therefore, it is imperative that these patients are provided additional means of protection to the virus. After reviewing the evidence, we have the following recommendations to maximize the protection of vulnerable patients with hematologic malignancies during the current phase of the COVID-19 pandemic.

One set of recommendations is focused on patients with hematologic malignancies. Despite the risks during the COVID-19 pandemic and the detrimental effects of many treatments on protection to the virus, patients with hematologic malignancies should receive the treatments for their condition. In some cases, the start of the treatment could be delayed to allow for initial or booster COVID-19 vaccination. To deliver patients' treatments safely, health care providers should offer patients COVID-19 testing before starting on B-cell–depleting therapies and surveillance COVID-19 testing during the therapy. Despite not being recommended for the general population, checking anti–SARS-CoV-2 spike protein antibody levels after COVID-19 vaccination would be warranted in patients with hematologic malignancies to discern patients who had or did not have seroconversion with the vaccine. This recommendation would require further research to determine which levels of anti-spike proteins would be considered to be protective to the COVID-19 disease. Research is also urgently needed to test different COVID-19 vaccine formulations, doses, repeated rounds of immunization, and heterologous boosting in patients with hematologic malignancies without seroconversion after standard COVID-19 vaccination. Passive immunity prophylaxis, with the administration of anti–COVID-19 monoclonal antibodies, convalescent serum,

RECOMMENDATIONS TO MAXIMIZE THE PROTECTION OF PATIENTS WITH HEMATOLOGIC MALIGNANCIES DURING THE CURRENT PHASE OF THE COVID-19 PANDEMIC

Recommendations focused on patients with hematologic malignancies:

- Plan to proceed with treatments for hematologic malignancies despite the COVID-19 pandemic.
- If feasible, consider a temporary delay in the start of therapy to allow for COVID-19 vaccination.
- Offer frequent COVID-19 testing, at baseline and during therapy.
- Provide priority administration of additional doses of COVID-19 vaccines to patients with hematologic malignances.
- Encourage research to define the levels of antibodies to the SARS-CoV-2 spike protein that are protective to the development of COVID-19 (following robust assay performance characteristics), in order to offer anti-spike serologic testing to patients with hematologic malignancies post–COVID-19 vaccination to assess their level of protection.
- Increase research testing of COVID-19 vaccine formulations, higher doses, repeated rounds of immunization, and heterologous boosting to increase the rate of seroconversions.
- Increase research testing of passive immunity prophylaxis (administration of COVID-19–neutralizing monoclonal antibodies, convalescent serum, or serum from vaccinated persons).
- If infected with SARS-CoV-2, introduce early treatments with monoclonal antibodies and convalescent plasma and with antiviral therapies.

Recommendations focused on health care facilities, hospitals, and clinics taking care of patients with hematologic malignancies:

- Have a mandate for 100% vaccination of all the staff of health care systems taking care of patients with hematologic malignancies and post the information publicly so that patients can be well-informed on the immunization status of their caretakers.
- Provide priority administration of additional doses of COVID-19 vaccines to health care workers to maintain high levels of seroconversion.
- Continue programs of frequent COVID-19 testing even in fully vaccinated people.
- Continue to use face masks, socially distance, and avoid close contact with nonvaccinated individuals.

Recommendations focused on caretakers and close household contacts of patients with hematologic malignancies:

- 100% vaccination of all persons 12 years or older.
- Provide priority administration of additional doses of COVID-19 vaccines to caretakers to maintain high levels of seroconversion.
- Continue programs of frequent COVID-19 testing even in fully vaccinated people.
- Continue to use face masks, socially distance, and avoid close contact with nonvaccinated individuals when outside the household.

Recommendations focused on public policy:

- Invest in surveillance programs in patients with hematologic malignancies receiving B- or T-cell–directed therapies, with frequent testing of the patients and caregivers to detect potential new SARS-CoV-2 variants.

or serum from vaccinated persons, could be a way to protect immunocompromised patients who cannot avoid exposure. Early experience using convalescent plasma in patients with hematologic malignancies with COVID-19 suggests that it decreases the mortality rates of patients with the most severe disease (33). Therefore, if patients with hematologic malignancies are infected with SARS-CoV-2, they should be promptly offered treatment with monoclonal antibodies and convalescent plasma and with antiviral therapies.

Another set of recommendations pertains to the people around the patients with hematologic malignancies, in particular, their physicians, nurses, caretakers, and close house contacts. Health care systems that take care of patients with hematologic malignancies should have a mandate for 100% vaccination of all staff and should post the information publicly so that patients can be well-informed on the immunization status of their caretakers. It is hard to think that health care workers who are not vaccinated by choice could be taking care of patients whom they are voluntarily putting at risk of severe complications and death from COVID-19. With the increasing evidence that protective immunity to COVID-19 decreases over time after vaccination, there should be priority administration of additional doses for caregivers and health care workers taking care of patients with hematologic malignancies. Patients with hematologic malignancies, their caregivers, and health care workers should continue to use face masks, socially distance, and avoid close contact with unvaccinated individuals; the only unvaccinated people in the society right now should be children under 12 years old for whom the safety of COVID-19 vaccines has not yet been established. Household contacts should be offered frequent COVID-19 testing, in particular if there are children in the house (Fig. 2).

The evidence of low seroconversion rates, correlated with low virus-neutralizing antibodies and suboptimal antiviral T-cell responses in patients with hematologic malignancies, raises questions about public policy. Even if high levels of herd immunity are achieved in society, it would still leave behind a population of vulnerable patients with immunosuppression where there could be evolution of the virus into new variants with increased virulence that could result in second waves of infections in the population that was immune to

Figure 2. Full vaccination in the majority of potential contacts of a patient with a hematologic malignancy with low anti–SARS-CoV-2 spike protein IgG serologic responses to COVID-19 vaccination would prevent the spread of SARS-CoV-2. **A,** A population of patients with suboptimal immunity to SARS-CoV-2, with some persons not vaccinated (pink, both adults and children), some persons with decreased antibody levels after vaccination (light blue), some persons without face masks with different levels of immunity to the virus, a person with COVID-19 (red), and a person with a hematologic malignancy without ability to mount full protection to COVID-19 despite vaccination (purple, in the center). In this setting, the SARS-CoV-2 virus can make its way from the infected person to the vulnerable patient with a hematologic malignancy without seroconversion after full COVID-19 vaccination. **B,** An alternate scenario, where all caregivers and health care workers taking care of a patient with hematologic malignancy are fully immune to COVID-19 and cannot pass the virus to the vulnerable patient with a hematologic malignancy. The only people without immunity to the SARS-CoV-2 virus in this scenario are children under the age of 12 and the person with the hematologic malignancy.

the prior SARS-CoV-2 variants (34). The emergence of SARS-CoV-2 variants has already been observed in COVID-19–infected patients with hematologic malignancies, especially in those patients with long-term infections (34). An argument should be made to invest in surveillance programs in patients with hematologic malignancies receiving B- or T-cell–directed therapies, with frequent testing of the patients and caregivers.

In conclusion, patients with certain hematologic malignancies are particularly vulnerable during the COVID-19 pandemic, and require additional measures to protect them from this and other viral infections to allow them to proceed with the treatment of their malignancies.

Authors' Disclosures

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REFERENCES

1. Addeo A, Shah PK, Bordry N, Hudson RD, Albracht B, Di Marco M, et al. Immunogenicity of SARS-CoV-2 messenger RNA vaccines in patients with cancer. Cancer Cell 2021;39:1091–8.
2. Greenberger LM, Saltzman LA, Senefeld JW, Johnson PW, DeGennaro LJ, Nichols GL. Antibody response to SARS-CoV-2 vaccines in patients with hematologic malignancies. Cancer Cell 2021;39:1031–3.
3. Ribas A, Sengupta R, Locke T, Zaidi SK, Campbell KM, Carethers JM, et al. Priority COVID-19 vaccination for patients with cancer while vaccine supply is limited. Cancer Discov 2021;11:233–6.
4. Tamari R, Politikos I, Knorr DA, Vardhana SA, Young JC, Marcello LT, et al. Predictors of humoral response 1 to SARS-CoV-2 vaccination after hematopoietic cell transplantation and CAR T-cell therapy. Blood Cancer Discov 2021;2:577–85.
5. Herishanu Y, Avivi I, Aharon A, Shefer G, Levi S, Bronstein Y, et al. Efficacy of the BNT162b2 mRNA COVID-19 vaccine in patients with chronic lymphocytic leukemia. Blood 2021;137:3165–73.
6. Parry H, McIlroy G, Bruton R, Ali M, Stephens C, Damery S, et al. Antibody responses after first and second Covid-19 vaccination in patients with chronic lymphocytic leukaemia. Blood Cancer J 2021;11:136.
7. Roeker LE, Knorr DA, Thompson MC, Nivar M, Lebowitz S, Peters N, et al. COVID-19 vaccine efficacy in patients with chronic lymphocytic leukemia. Leukemia 2021;35:2703–5.
8. Ehmsen S, Asmussen A, Jeppesen SS, Nilsson AC, Osterlev S, Vestergaard H, et al. Antibody and T cell immune responses following mRNA COVID-19 vaccination in patients with cancer. Cancer Cell 2021;39:1034–6.
9. Benjamini O, Rokach L, Itchaki G, Braester A, Shvidel L, Goldschmidt N, et al. Safety and efficacy of BNT162b mRNA Covid19 vaccine in patients with chronic lymphocytic leukemia. Haematologica 2021 Jul 29 [Epub ahead of print].

10. Pimpinelli F, Marchesi F, Piaggio G, Giannarelli D, Papa E, Falcucci P, et al. Fifth-week immunogenicity and safety of anti–SARS-CoV-2 BNT162b2 vaccine in patients with multiple myeloma and myeloproliferative malignancies on active treatment: preliminary data from a single institution. J Hematol Oncol 2021;14:81.
11. Van Oekelen O, Gleason CR, Agte S, Srivastava K, Beach KF, Aleman A, et al. Highly variable SARS-CoV-2 spike antibody responses to two doses of COVID-19 RNA vaccination in patients with multiple myeloma. Cancer Cell 2021;39:1028–30.
12. Avivi I, Balaban R, Shragai T, Sheffer G, Morales M, Aharon A, et al. Humoral response rate and predictors of response to BNT162b2 mRNA COVID19 vaccine in patients with multiple myeloma. Br J Haematol 2021.
13. Chung DJ, Shah GL, Devlin SM, Ramanathan LV, Doddi S, Pessin MS, et al. Disease- and therapy-specific impact on humoral immune responses to COVID-19 vaccination in hematologic malignancies. Blood Cancer Discov 2021;2:568–76.
14. Agha M, Blake M, Chilleo C, Wells A, Haidar G. Suboptimal response to COVID-19 mRNA vaccines in hematologic malignancies patients. medRxiv 2021.04.06.21254949 [Preprint]. 2021. Available from: https://doi.org/10.1101/2021.04.06.21254949.
15. Stampfer SD, Goldwater MS, Jew S, Bujarski S, Regidor B, Daniely D, et al. Response to mRNA vaccination for COVID-19 among patients with multiple myeloma. Leukemia 2021 Jul 29 [Epub ahead of print].
16. Ollila TA, Lu S, Masel R, Zayac A, Paiva K, Rogers RD, et al. Antibody response to COVID-19 vaccination in adults with hematologic malignant disease. JAMA Oncol 2021 Aug 11 [Epub ahead of print].
17. Perry C, Luttwak E, Balaban R, Shefer G, Morales MM, Aharon A, et al. Efficacy of the BNT162b2 mRNA COVID-19 vaccine in patients with B-cell non-Hodgkin lymphoma. Blood Adv 2021;5:3053–61.
18. Gurion R, Rozovski U, Itchaki G, Gafter-Gvili A, Leibovitch C, Raanani P, et al. Humoral serologic response to the BNT162b2 vaccine is abrogated in lymphoma patients within the first 12 months following treatment with anti-CD2O antibodies. Haematologica 2021 Jul 29 [Epub ahead of print].
19. Lim SH, Campbell N, Johnson M, Joseph-Pietras D, Collins GP, O'Callaghan A, et al. Antibody responses after SARS-CoV-2 vaccination in patients with lymphoma. Lancet Haematol 2021;8:e542–e4.
20. Ghandili S, Schonlein M, Lutgehetmann M, Schulze Zur Wiesch J, Becher H, Bokemeyer C, et al. Post-vaccination anti–SARS-CoV-2-antibody response in patients with multiple myeloma correlates with low CD19+ B-lymphocyte count and anti-CD38 treatment. Cancers 2021;13:3800.
21. Terpos E, Trougakos IP, Gavriatopoulou M, Papassotiriou I, Sklirou AD, Ntanasis-Stathopoulos I, et al. Low neutralizing antibody responses against SARS-CoV-2 in older patients with myeloma after the first BNT162b2 vaccine dose. Blood 2021;137:3674–6.
22. Thakkar A, Gonzalez-Lugo JD, Goradia N, Gali R, Shapiro LC, Pradhan K, et al. Seroconversion rates following COVID-19 vaccination among patients with cancer. Cancer Cell 2021;39:1081–90.
23. Diefenbach C, Caro J, Koide A, Grossbard M, Goldberg JD, Raphael B, et al. Impaired humoral immunity to SARS-CoV-2 vaccination in non-Hodgkin lymphoma and CLL patients. medRxiv 2021.06.02.21257804 [Preprint]. 2021. Available from: https://doi.org/10.1101/2021.06.02.21257804.
24. Ghione P, Gu JJ, Attwood K, Torka P, Goel S, Sundaram S, et al. Impaired humoral responses to COVID-19 vaccination in patients with lymphoma receiving B-cell directed therapies. Blood 2021;138:811–4.
25. Maneikis K, Sablauskas K, Ringeleviciute U, Vaitekenaite V, Cekauskiene R, Kryzauskaite L, et al. Immunogenicity of the BNT162b2 COVID-19 mRNA vaccine and early clinical outcomes in patients with haematological malignancies in Lithuania: a national prospective cohort study. Lancet Haematol 2021;8:e583–e92.
26. Pleyer C, Ali MA, Cohen JI, Tian X, Soto S, Ahn IE, et al. Effect of Bruton tyrosine kinase inhibitor on efficacy of adjuvanted recombinant hepatitis B and zoster vaccines. Blood 2021;137:185–9.
27. Branagan AR, Duffy E, Gan G, Li F, Foster C, Verma R, et al. Tandem high-dose influenza vaccination is associated with more durable serologic immunity in patients with plasma cell dyscrasias. Blood Adv 2021;5:1535–9.
28. Dhodapkar MV, Dhodapkar KM, Ahmed R. Viral immunity and vaccines in hematologic malignancies: implications for COVID-19. Blood Cancer Discov 2021;2:9–12.
29. Greenberger LM, Saltzman LA, Senefeld JW, Johnson PW, DeGennaro LJ, Nichols G. Anti-spike antibody response to SARS-CoV-2 booster vaccination in patients with B cell-derived hematologic malignancies. Cancer Cell 2021 Sep 21 [Epub ahead of print].
30. Redjoul R, Le Bouter A, Parinet V, Fourati S, Maury S. Antibody response after third BNT162b2 dose in recipients of allogeneic HSCT. Lancet Haematol 2021 Sep 3 [Epub ahead of print].
31. Bange EM, Han NA, Wileyto P, Kim JY, Gouma S, Robinson J, et al. CD8(+) T cells contribute to survival in patients with COVID-19 and hematologic cancer. Nat Med 2021;27:1280–9.
32. Israelow B, Mao T, Klein J, Song E, Menasche B, Omer SB, et al. Adaptive immune determinants of viral clearance and protection in mouse models of SARS-CoV-2. bioRxiv 2021.05.19.444825 [Preprint]. 2021. Available from: https://doi.org/10.1101/2021.05.19.444825.
33. Thompson MA, Henderson JP, Shah PK, Rubinstein SM, Joyner MJ, Choueiri TK, et al. Association of convalescent plasma therapy with survival in patients with hematologic cancers and COVID-19. JAMA Oncol 2021;7:1167–75.
34. Corey L, Beyrer C, Cohen MS, Michael NL, Bedford T, Rolland M. SARS-CoV-2 variants in patients with immunosuppression. N Engl J Med 2021;385:562–6.