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ORIGINAL ARTICLE

Survival in multiple myeloma and SARS-COV-2 infection through the COVID-19 pandemic: Results from the EPICOVIDEHA registry

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Abstract

Patients affected by multiple myeloma (MM) have an increased risk of severe acute respiratory syndrome coronavirus type 2 (SARS-CoV-2) infection and subsequent coronavirus (20)19 disease (COVID-19)-related death. The changing epidemiological and therapeutic scenarios suggest that there has been an improvement in severity and survival of COVID-19 during the different waves of the pandemic in the general population, but this has not been investigated yet in MM patients. Here we analyzed a large cohort of 1221 patients with MM and confirmed SARS-CoV-2 infection observed between February 2020, and August 2022, in the EPICOVIDEHA registry from 132 centers around the world. Median follow-up was 52 days for the entire cohort and 83 days for survivors. Three-hundred and three patients died (24%) and COVID-19 was the primary reason for death of around 89% of them. Overall survival (OS) was significantly higher in vaccinated patients with both stable and active MM versus unvaccinated, while only a trend favoring vaccinated patients was observed in subjects with responsive MM. Vaccinated patients with at least 2 doses showed a better OS than those with one or no vaccine dose. Overall, according to pandemic waves, mortality rate decreased over time from 34% to 10%. In multivariable analysis, age, renal failure, active disease, hospital, and intensive care unit admission, were independently associated with a higher number of deaths, while a neutrophil count above 0.5×10^9/L was found to be protective. This data suggests that MM patients remain at risk of SARS-CoV-2 infection even in the vaccination era, but their clinical outcome, in terms of OS, has progressively improved throughout the different viral phases of the pandemic.

KEYWORDS
COVID-19, hematological malignancy, multiple myeloma, SARS-CoV-2

1 | INTRODUCTION

During the severe acute respiratory syndrome coronavirus type 2 (SARS-CoV-2) pandemic, infected patients with hematologic malignancies (HM) have clearly shown a significantly poorer outcome compared to the general population,[1–3] mainly due to inherent immunosuppression and effects of some treatments. In this regard, multiple myeloma (MM) represents a good example, since in this neoplastic disorder both humoral and cellular immunity are particularly compromised because of malignancy itself and plasma cells-directed therapies. Moreover, MM is characterized by high incidence in the elderly; this fact further contributes to increase the risk of infections[4] and, specifically, of poorer outcome of SARS-CoV-2 infection, particularly in those patients with high risk, active/progressive disease, and/or renal failure.[2,5–8]

Thus, vaccines against SARS-CoV-2 have become the most important preventive strategy to protect these patients from severe complications deriving from SARS-CoV-2 infections.[9] However, MM patients may develop lower antibody responses to anti SARS-CoV-2 vaccines, particularly after anti-CD38 and anti–B-cell maturation antigen (BCMA) drugs[10–18] or transplant/CAR-T procedures.[19–23] Therefore they remain at higher risk of breakthrough infections (13%–15%), compared to non-cancer patients (approximatively 4%), that are linked to still significant morbidity and mortality.[24–26] On the other hand, studies would suggest that severity of disease and mortality rates are ameliorated also in this category of patients, mainly thanks to appropriate vaccination policies.[2,27] Furthermore, some preliminary, encouraging data, has been reported about preexposure prophylaxis with monoclonal antibodies against SARS-CoV-2[28–30] and early start after SARS-CoV-2 infection with antiviral drugs[31,32] to prevent the progression to critical disease in severely immuno-compromised populations, such as MM patients.

Several investigations published about MM patients with SARS-CoV-2 infection during the first phases of pandemic have reported impressive mortality rates following infection up to 55%[2,5–8] and consensus guidelines have been produced to manage these parts of pandemic.[33] Here we describe the largest survey on MM patients with SARS-CoV-2 infection, also including individuals developing COVID-19 during the most recent waves of pandemic, with

TABLE 1 Demographic and clinical features of 1221 patients with multiple myeloma at the time of SARS-CoV-2 infection diagnosis.

	N	%
Sex		
Female	519	42.5
Male	702	57.5
Age, years		
Median (IQR)	68 (60–76)	NA
Range	30–95	NA
Comorbidities		
0	410	33.5
1	415	34
2	234	19.2
≥3	162	13.3
Comorbidities, type		
Chronic cardiopathy	467	38.2
Chronic pulmonary disease	177	14.5
Diabetes mellitus	192	15.7
Liver disease	44	3.6
Obesity	95	7.8
Renal impairment	188	15.4
Smoking history	148	12.1
No risk factor identified	404	33.1
Vaccination status		
One dose	24	2
Two doses	143	11.7
Three doses	225	18.4
Four doses	24	2
Not vaccinated	805	65.9
Neutrophils, $\times 10^9$/L		
≤0.5	30	2.5
0.501–0.999	53	4.3
≥1	1003	82.2
Lymphocytes, $\times 10^9$/L		
≤0.2	121	9.9
0.201–0.499	203	16.6
≥0.5	897	73.5
MM status		
Controlled disease	592	48.5
Stable disease	201	16.5
Active disease	390	31.9
Unknown	38	3.1
Last/ongoing treatment		
Allo-HSCT	2	0.2

(Continues)

TABLE 1 (Continued)

	N	%
Auto-HSCT	61	5
CAR-T	4	0.3
IMids (thalidomide, lenalidomide, pomalidomide) and proteasome inhibitors (bortezomib, carfilzomib, ixazomib)	698	57.2
Conventional chemotherapy (cyclophosphamide, melphalan)	50	4.1
Monoclonal antibodies (daratumumab, isatuximab, elotuzumab)	247	20.2
Antibody-drug coniugate (belantamab mafodotin) and bispecific antibodies (teclistamab, talquetamab, cevostamab)	20	1.6
Supportive/Palliative	34	2.8
Unknown	19	1.6
No treatment	86	7
Symptoms		
Pulmonary	451	36.9
Pulmonary + extrapulmonary	277	22.7
Extrapulmonary	224	18.4
Screening	269	22
SARS-CoV-2 infection severity		
Critical infection	169	13.8
Severe infection	471	38.6
Mild infection	350	28.7
Asymptomatic	231	18.9
Stay during SARS-CoV-2 infection		
Admitted to hospital	775	63.5
Duration of stay in hospital, days median (IQR)	12 (7–120)	NA
Range	1–120	NA
Admitted to ICU	169	13.8
Duration of ICU stay, days median (IQR)	10 (6–14)	NA
Range	1–56	NA
Invasive MV	107	8.8
Non-invasive MV	61	5
At home	446	36.5
SARS-CoV-2 infection treatment		
No specific treatment reported	270	22.1
Antivirals +/− corticosteroids +/− plasma	135	11.1
Antivirals + monoclonal antibodies +/− corticosteroids +/− plasma	23	1.9
Monoclonal antibodies +/− corticosteroids +/− plasma	84	6.9
Plasma +/− corticosteroids	10	0.8
Corticosteroids	94	7.7
Unknown	605	49.5
Outcome		
Alive	918	75.2
Observation time, days median (IQR)	83.5 (28–162)	NA

TABLE 1 (Continued)

	N	%
Range	0–741	NA
Dead	303	24.8
Observation time, days median (IQR)	13 (7–30)	NA
Range	0–763	NA
Reason for death		
COVID-19	196	64.7
COVID-19 + multiple myeloma	72	23.8
Multiple myeloma +/− other reasons	35	11.5

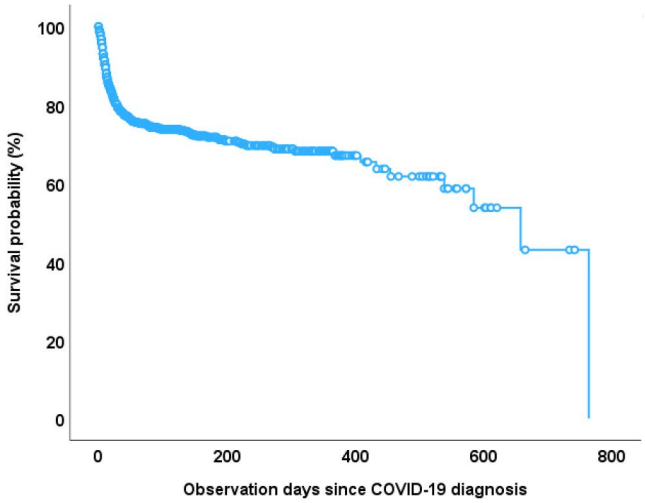


FIGURE 1 Overall survival (OS) of patients with SARS-CoV-2 infection and multiple myeloma.

particular attention to overall survival (OS) after the introduction of vaccines and the progressive appearance of new viral variants of concern (VOC).

2 | METHODS

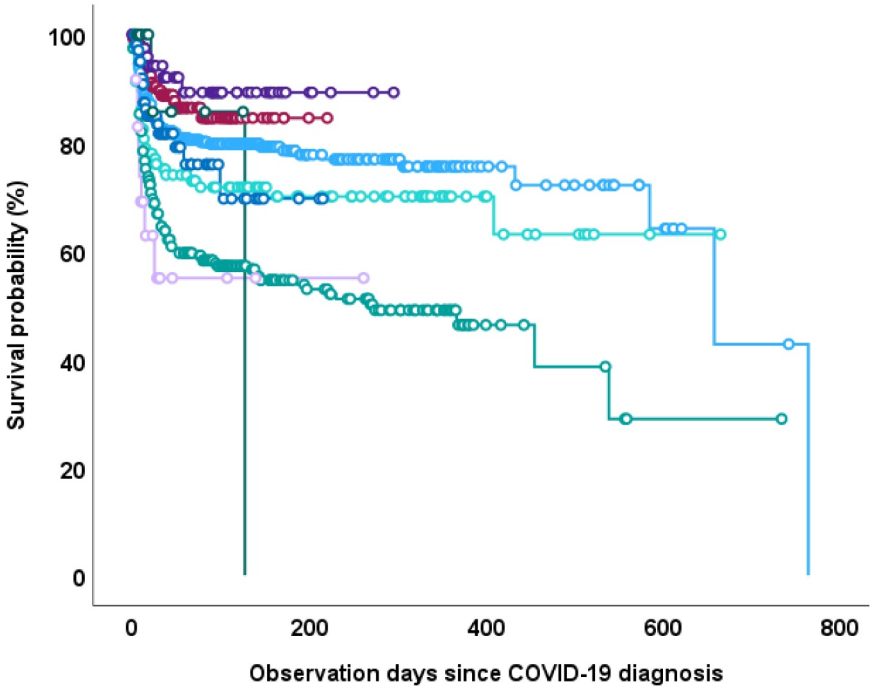
EPICOVIDEHA (www.clinicaltrials.gov; ID NCT04733729), is an international open web-based registry for patients with HM and SARS-CoV-2 infection, initiated in February 2020, by members of the Scientific Working Group Infection in Hematology of the European Hematology Association.[34] It was approved by the local ethics committee of the Fondazione Policlinico Universitario Agostino Gemelli - IRCCS, Università Cattolica del Sacro Cuore of Rome, Italy (ID 3226). All consecutive MM patients diagnosed with SARS-CoV-2 infection were potentially captured and registered in this web-based registry. The respective local ethics committee of each participating institution approved as appropriate. The electronic case report form is accessible online via www.clinicalsurveys.net (EFS Summer 2021, TIVIAN GmbH, Cologne, Germany).[35] Each entry was reviewed and validated by infectious diseases and hematology experts. Patient conditions at SARS-CoV-2 infection diagnosis (i.e., age, sex, comorbidities, MM status and clinical management, vaccination status, SARS-CoV-2 infection management and outcome) were recorded. Disease status of MM at SARS-CoV-2 infection onset and last follow up was defined as active (progressive disease, newly diagnosed MM), controlled (at least partial response or stable disease), according to IMWG criteria and based on reports from the respective participating institution. COVID-19 severity was graded according to international standards, as previously described.[36]

The primary objective of this study was to evaluate OS and its possible changes of MM patients with SARS-CoV-2 infection during the different epidemic waves. The secondary objective was to evaluate the factors possibly affecting OS, mainly according to disease phase, laboratory analyses, most recent MM treatment received, comorbidities, vaccine status, severity, and treatments of COVID-19.

Continuous data are presented as median, interquartile range (IQR) and absolute range, and categorical variables are as counts and percentages. Cox regression model was used for mortality analysis. Variables with a *p*-value of 0.1 in the univariable analyses were included in the multivariable analysis. A backward Wald method was used in the multivariable Cox regression model. The Kaplan-Meier survival curve was also used to assess mortality. A log-rank test was performed to compare the survival probabilities of patients included in the different models. Statistical significance was defined as a *p*-value of 0.05. SPSSv25.0 (IBM Corp.) was used for statistical analysis.

3 | RESULTS

Between February 2020, and August 2022, 1221 adult patients with MM and confirmed SARS-CoV-2 infection were reported in the EPICOVIDEHA registry by 132 centers from 32 countries around the world, mainly in Europe (Supplemental Table S1). Demographic and clinical characteristics of patients are reported in Table 1. The median age at the time of SARS-CoV-2 infection was 68 years (interquartile range [IQR]: 60–76), with a male predominance (702, 57.5%). Eight hundred eleven patients (66.4%) had at least one underlying comorbidity, mostly (407, 38.2%) a cardiovascular disease. With



Overall log-rank test p value <0.001

	Controlled + Not vaccinated	Controlled + Vaccinated	Stable + Not vaccinated	Stable + Vaccinated	Active + Not vaccinated	Active + Vaccinated	Unknown + Not vaccinated
Controlled + Vaccinated	0.078						
Stable + Not vaccinated	0.077	**0.001**					
Stable + Vaccinated	**0.047**	0.409	**0.002**				
Active + Not vaccinated	**<0.001**	**<0.001**	**0.005**	**<0.001**			
Active + Vaccinated	0.495	**0.041**	0.359	**0.020**	**0.003**		
Unknown + Not vaccinated	**<0.001**	**<0.001**	0.085	**<0.001**	0.376	**0.008**	
Unknown + Vaccinated	0.864	0.431	0.603	0.207	0.255	0.916	0.175

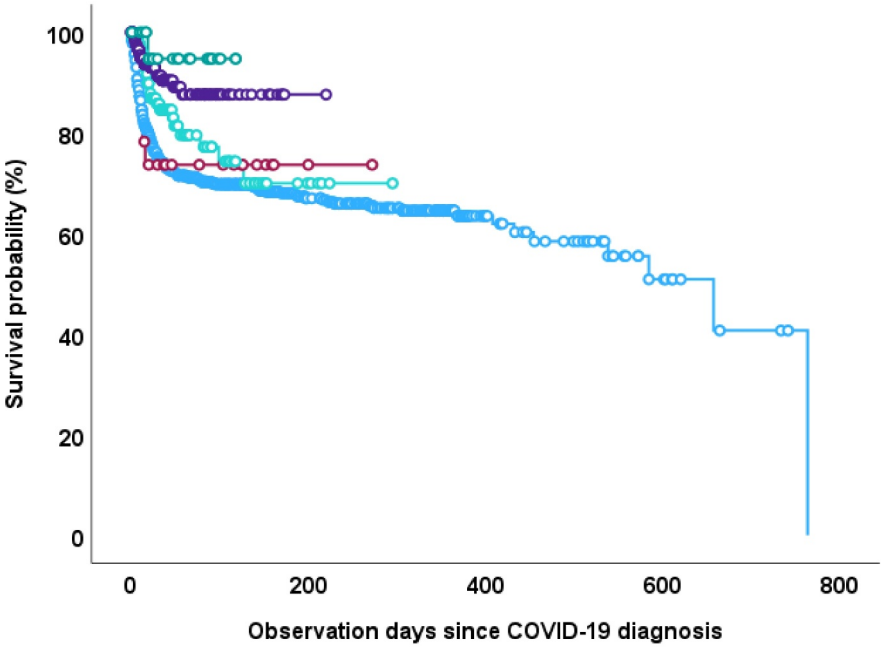
FIGURE 2 Survival probability by malignancy- and vaccine-status.

regard to vaccination status against SARS-CoV-2, 805 patients (65.9%) were not vaccinated when they were infected, while 416 (34.1%) had received at least one dose, and 225 (18.4%) had received three doses. At infection onset, 30 (2.5%) and 121 (9.9%) patients had neutrophil and lymphocyte counts below 0.5×10^9/L and 0.2×10^9/L, respectively.

Concerning malignancy status, 793 patients (64.9%) had controlled or stable disease, while in 390 (31.9%) MM was active, including 56 newly diagnosed patients, 66.1% of whom were not vaccinated. Regarding last MM treatment before SARS-CoV-2 infection, most patients (57.2%) had received IMids (thalidomide, lenalidomide, pomalidomide) and proteasome inhibitors (bortezomib, carfilzomib, ixazomib), followed (20.2%) by monoclonal antibodies (daratumumab, isatuximab, elotuzumab); 61 patients (5%) had received autologous stem cell transplantation, 2 patients (0.2%) allogenic stem cell transplantation (Allo-SCT), and 4 patients (0.3%) CAR-T cell therapy.

At SARS-CoV-2 infection onset, 728 patients (59.7%) had pulmonary symptoms, 224 (18.4%) exhibited only extra-pulmonary symptoms and 269 (22%) were incidentally diagnosed after screening for SARS-CoV-2 infection. COVID-19 was critical in 169 patients (13.8%), severe in 471 (38.6%), mild in 350 (28.7%), and asymptomatic in the remaining cases (18.9%). Four hundred and forty-six patients (36.5%) could stay at home and were managed as outpatients during SARS-CoV-2 infection, while 775 patients (63.5%) were hospitalized for a median of 12 days (IQR: 7–120). One hundred and sixty-nine patients (13.8%) were admitted to an intensive care unit (ICU) for a median stay of 10 days (IQR: 6–14); 107 of them required invasive mechanical ventilation (63.3%; 8.8% of all patients).

No specific targeted drug for SARS-CoV-2 infection was used in 270 patients (22.1%), while in 346 (28.3%) individuals antivirals, monoclonal antibodies, corticosteroids, and convalescent plasma as single or combined therapies were given. However, in 605 (49.5%) patients, it was not reported whether therapies against SARS-CoV-2



Overall log-rank test p value <0.001

	Not vaccinated	One dose	Two doses	Three doses
One dose	0.800			
Two doses	**0.034**	0.488		
Three doses	**<0.001**	**0.029**	0.059	
Four doses	**0.027**	**0.043**	0.127	0.401

FIGURE 3 Survival probability by vaccine doses.

infection were employed. Thirty-seven cases of reinfections were reported, but data about these patients were fragmentary and, therefore, not analyzed in detail. After a median follow-up of 52 days (IQR: 16–143; range: 0–763) for the entire cohort and 83.5 days for survivors, 303 patients died (24.8%); mortality at 30 days and at 100 days post SARS-CoV-2 infection diagnosis in the whole cohort was 18.8% and 24.5% respectively (Figure 1). The reported primary reason for death was COVID-19 in 196 (64.7%) patients, a combination of MM and COVID-19 in 72 (23.8%) and a combination of MM and other reasons in 35 (11.5%).

Estimated OS was significantly higher in vaccinated patients with both stable and active MM versus the unvaccinated (Figure 2, $p = 0.002$ and $p = 0.003$, respectively), while only a trend favoring vaccinated patients was observed in subjects with controlled disease ($p = 0.078$). A sub-analysis focused on the number of vaccine doses received, and revealed that vaccinated patients with ≥2 doses (Figure 3) showed a better outcome (particularly with 3 or 4 doses) than those with ≤1 dose.

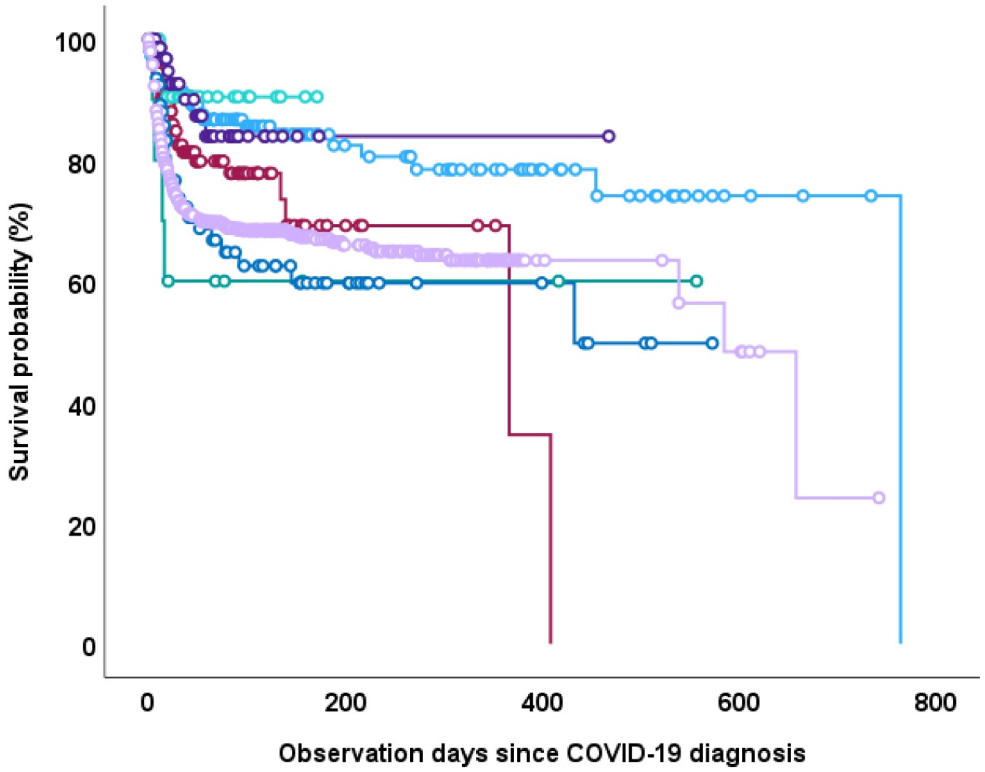
Finally, when treatment for SARS-CoV-2 infection was evaluated, we found that OS was significantly longer in patients receiving a combination of antivirals and monoclonal antibodies, with or without adjunct corticosteroids and/or plasma (Figure 4).

Overall, according to pandemic waves due to SARS-CoV-2 variants, mortality rates decreased over time (Wildtype (WT): 34%; Alpha/Beta/Gamma: 25.3%; Delta: 20.4%; Omicron: 10.2%) (Supplemental Table S2). In particular, differences observed were statistically significant between WT and Omicron waves (p=<0.001) and between Delta and Omicron waves ($p = 0.042$), respectively (Figure 5).

At univariable analysis (Table 2) age, chronic cardiopathy, chronic pulmonary disease, renal failure, active MM at SARS-CoV-2 infection onset, use of steroids, hospital admission and ICU admission were significantly associated with a worse OS. On the contrary, neutrophil or lymphocyte count above 0.5×10^9/L, extrapulmonary symptoms or absence of symptoms, use of antivirals +/− monoclonal antibodies and ≥2 vaccine doses were associated with reduced mortality. However, at multivariable Cox regression analysis, only age, renal failure, active disease, hospital and ICU admission were independently associated with poor survival. At the opposite, neutrophil count above 0.5×10^9/L was found to be protective.

4 | DISCUSSION

Here we present, to the best of our knowledge, the largest survey of MM patients infected by SARS-CoV-2, followed during the different phases of the COVID-19 pandemic, with the longest follow-up encompassing subsequent infection periods with different viral VOC (WT, Alpha/Beta/Gamma, Delta, and Omicron). Overall, our data suggest that MM patients remain vulnerable to SARS-CoV-2 infection even in the vaccination era, but also that these patients have progressively improved their OS throughout the different viral phases of pandemic.



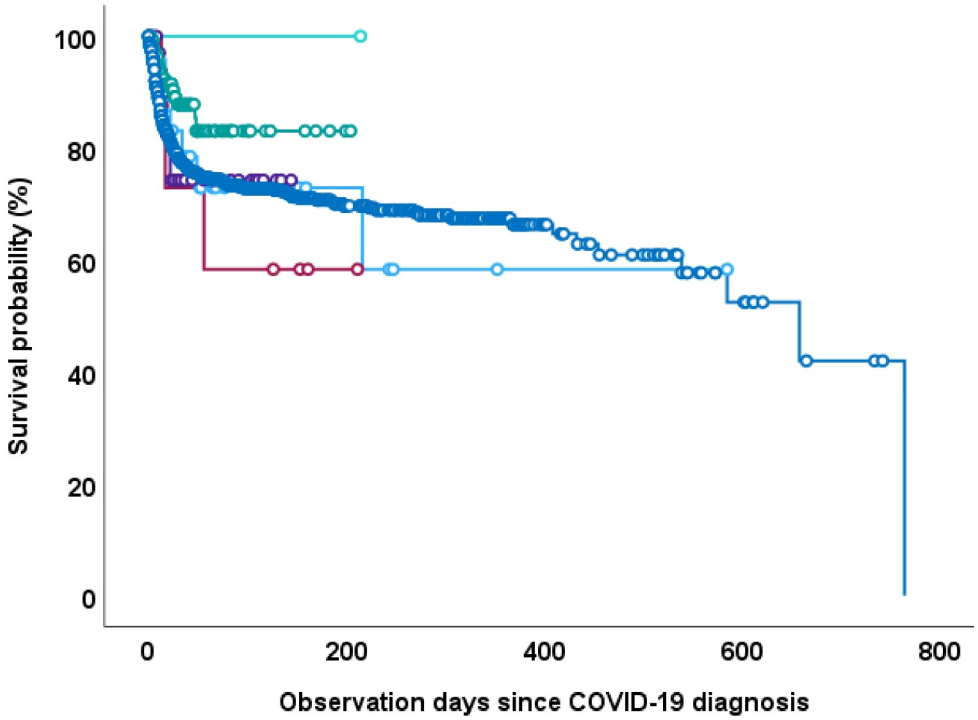
Overall log-rank test p value <0.001

	No specific treatment	Antivirals +/- corticosteroids +/- plasma	Antivirals + monoclonal antibodies +/- corticosteroids +/- plasma	Monoclonal antibodies +/- corticosteroids +/- plasma	Plasma +/- corticosteroids	Corticosteroids
Antivirals +/- corticosteroids +/- plasma	**0.015**					
Antivirals + monoclonal antibodies +/- corticosteroids +/- plasma	0.668	0.235				
Monoclonal antibodies +/- corticosteroids +/- plasma	0.770	0.109	0.712			
Plasma +/- corticosteroids	**0.025**	0.589	**0.027**	**0.014**		
Corticosteroids	**<0.001**	0.210	**0.047**	**0.007**	0.617	
Unknown	**<0.001**	0.085	0.053	**0.003**	0.531	0.743

FIGURE 4 Survival probability by SARS-CoV-2 infection treatment.

Indeed, in our study, the majority of MM patients (52.4%) showed a critical/severe infection requiring hospitalization (63.5%), while the global mortality rate following infection (24.8%), due to COVID-19 in the large majority of cases, was coherent with that reported in previous studies (ranging from 22% to 54.8%) and significantly higher than in the general population and in patients with other malignancies.[5–8] In particular, hospital and/or ICU admission had the most significant negative impact on COVID-19 outcome, showing a strong correlation with an increased mortality at multivariable analysis, along with older age, renal failure and active MM disease. By contrast, neutrophil count above 0.5×10^9/L was found to be significantly protective. Notably, most recent line of treatment received, other comorbidities (including pulmonary disorders) and absolute lymphocyte count did not impact on OS at multivariable analysis.

Regarding anti-SARS-CoV-2 treatments, combination of antivirals and monoclonal antibodies (+/− steroids and/or plasma) apparently resulted in a better survival, but available data were too heterogeneous and imprecise to draw definitive conclusions. Curiously, and differently from recent data reported in the general population,[37] the use of steroids was associated with a worse outcome at univariate analysis, a fact that was not confirmed, however, at multivariable analysis. Steroid-related further immune-suppression, in addition to that intrinsic to MM, and concomitant treatments, could explain this quite unexpected finding that requires, however, further confirmation. Notably, while the effects of steroids in the



Overall log-rank test p value p=0.195

	Wild type	Alpha variant	Beta variant	Delta variant	Omicron variant
Alpha variant	0.475				
Beta variant	0.579	0.483			
Delta variant	0.862	0.480	0.588		
Omicron variant	0.294	0.136	0.668	0.208	
Not tested	0.985	0.567	0.547	0.784	**0.010**

FIGURE 5 Survival probability by COVID-19 waves (variants of concern).

inflammatory phase of SARS-CoV-2 infection needing oxygen administration would be positive, their use in the earlier viral infection phase not requiring oxygen therapy was reported to be associated to detrimental results.[37,38]

Overall, OS was significantly longer in vaccinated versus unvaccinated patients, including those with scarcely controlled disease, thus suggesting the possible efficacy of vaccines even in this population of patients, despite their generally described inadequate capacity of humoral immune response.[39–41] In particular, vaccinated patients with ≥2 doses showed a better OS than those unvaccinated or having receives only one dose, highlighting the need of a complete cycle of vaccination, also in individuals with MM, particularly in those with scarce immune-reaction after the first two doses.[42–45] Notwithstanding, even full vaccinations, though statistically significant at univariable analysis, did not enter into the multivariable model, where other clinical variables, in particular age, active disease, and COVID-19 severity requiring hospital/ICU admission, had a major impact. In this setting, more recent VOC,[46] reduced production of neutralizing antibodies[47,48] and impaired T-cell response,[49] as well increasing hybrid[50] and herd immunity in MM patients could have also played a role.

Above all, we observed that OS rates progressively improved throughout the different pandemic waves. In particular, mortality rates declined from first (34%) to last (10.2%) wave. The overall improvement likely reflects a combination of factors, mainly healthcare worker experience dealing with this type of patients, targeted treatments for symptomatic COVID-19, extensive vaccine policies, as well as detection of a larger number of asymptomatic/mild cases by screening programs. In this context, regarding the role of more recently prevalent VOC, in November 2021, the World Health Organization (WHO) declared the Omicron variant (B.1.1.529) of SARS-CoV-2, as a new VOC, while, since January 2022, BA.2.12.1, BA.4,

TABLE 2 Overall mortality predictors in patients with multiple myeloma and SARS-CoV-2 infection.

	Univariable				Multivariable			
			95% CI				95% CI	
	p Value	HR	Lower limit	Upper limit	*p* Value	HR	Lower limit	Upper limit
Sex								
Female	-	-	-	-				
Male	0.804	1.030	0.817	1.297				
Age	<0.001	1.031	1.019	1.042	**<0.001**	1.032	1.018	1.045
Comorbidities								
Chronic cardiopathy	<0.001	1.671	1.330	2.100	0.435	1.122	0.841	1.497
CPD	0.006	1.498	1.123	1.996	0.768	0.954	0.696	1.306
Diabetes mellitus	0.209	1.207	0.900	1.620				
Liver disease	0.728	1.108	0.622	1.975				
Obesity	0.747	0.932	0.609	1.427				
Renal failure	<0.001	2.226	1.720	2.881	**0.004**	1.526	1.143	2.038
Smoking history	0.120	1.286	0.936	1.767				
No risk factor	<0.001	0.551	0.419	0.724	0.956	1.010	0.706	1.445
Neutrophils								
<501	-	-	-	-	-	-	-	-
501–999	0.022	0.391	0.175	0.873	**0.036**	0.411	0.179	0.943
>999	0.014	0.496	0.284	0.866	0.053	0.557	0.308	1.007
Lymphocytes								
<201	-	-	-	-	-	-	-	-
201–499	0.334	0.835	0.580	1.203	0.723	0.933	0.636	1.368
>499	<0.001	0.481	0.349	0.663	0.111	0.757	0.538	1.066
Multile myeloma status								
Controlled disease	-	-	-	-	-	-	-	-
Stable disease	0.355	1.191	0.822	1.724	0.574	1.117	0.759	1.643
Active disease	<0.001	2.447	1.897	3.158	**<0.001**	1.655	1.256	2.182
Unknown	0.001	2.791	1.494	5.213	**0.043**	1.988	1.022	3.868
Symptoms due to SARS-CoV-2 infection (at onset)								
Pulmonary	-	-	-	-	-	-	-	-
Pulmonary + extrapulmonary	0.148	0.810	0.610	1.078	0.727	0.947	0.698	1.285
Extrapulmonary	<0.001	0.459	0.315	0.668	0.273	0.795	0.528	1.198
Screening	<0.001	0.554	0.401	0.765	0.455	1.143	0.805	1.622
SARS-CoV-2 vaccination status								
Not vaccinated	-	-	-	-	-	-	-	-
One dose	0.814	0.907	0.404	2.041	0.977	0.987	0.408	2.385
Two or more doses	<0.001	0.438	0.315	0.609	0.215	0.752	0.479	1.180
Stay during SARS-CoV-2 infection episode								
Home	-	-	-	-	-	-	-	-
Hospital	<0.001	9.299	5.483	15.772	**<0.001**	5.967	3.381	10.532
Intensive care unit	<0.001	26.887	15.666	46.144	**<0.001**	17.007	9.353	30.925

TABLE 2 (Continued)

	Univariable				Multivariable			
			95% CI				95% CI	
	p Value	HR	Lower limit	Upper limit	*p* Value	HR	Lower limit	Upper limit
SARS-CoV-2 infection treatment								
No specific treatment	-	-	-	-	-	-	-	-
AVs +/− corticosteroids +/− plasma	0.035	1.745	1.041	2.924	0.156	0.666	0.381	1.167
AVs + MoABs +/− corticosteroids +/− plasma	0.629	0.703	0.169	2.932	0.127	0.324	0.076	1.377
MoABs +/− corticosteroids +/− plasma	0.722	0.862	0.381	1.952	0.220	0.581	0.244	1.383
Corticosteroids +/− plasma	0.027	3.226	1.141	9.119	0.640	1.291	0.442	3.773
Corticosteroids	<0.001	2.627	1.600	4.311	0.710	0.904	0.530	1.542
Unknown	<0.001	2.458	1.696	3.561	0.794	1.059	0.688	1.630

Note: Bold values are statistically significant.

Abbreviations: AVs, antivirals; CI, confidence interval; CPD, chronic pulmonary disease; HR, Hazard ratio; MoABs, monoclonal antibodies; SARS-CoV-2, severe acute respiratory syndrome coronavirus type 2.

BA.5, BQ.1.1, and XBB.1 omicron VOC new sub-variants have become largely prevalent (BQ.1.1 and XBB.1, particularly Europe and the United States). All these variants exhibit higher transmissibility than previous ones and manifest multiple novel spike protein mutations that have raised concerns about clinical outcome of SARS-CoV-2 infection infected by these strains, antiviral treatments and vaccine efficiency in MM patients.[51,52] However, these more recent dominant Omicron SARS-CoV-2 variants usually also often induce mild or asymptomatic disease with respect to the first waves of pandemic, sustained by SARS-CoV-2 ancestral WT, alpha and delta strains (all currently considered "de-escalated" variants), thus mimicking, though clearly to a lesser extent, what has been observed in the general population and also in other types of hematological and non-hematological cancers.[3]

These findings suffer from the unavoidable limitations of the observational nature of the study and the heterogeneity of the examined population, that is, incomplete dataset regarding some laboratory features; lack of evidence about humoral and cellular response to vaccines and VOC; variability of MM and SARS-CoV-2 infection management, and diverse vaccine policies followed in different countries.

Notwithstanding, our data indicates that a combination of complete vaccination programs and an appropriate general management, possibly along with the emergence of more transmissible, but less aggressive VOC, have significantly improved OS of MM patients infected by SARS-CoV-2 during the pandemic waves that have occurred over time. However, despite these improvements and the recent declaration of the end of pandemic by WHO (5 May 2023), it should be remembered that MM patients remain at risk of breakthrough infections and severe related complications. It is, therefore, still mandatory to maintain attention on these individuals.[53] In this setting, the European Myeloma Network has recently provided an updated expert consensus to guide MM patient management also in this "post-pandemic" era.[54]

AUTHOR CONTRIBUTIONS

Pellegrino Musto, Jon Salmanton-García, Nicola Sgherza, Francesco Marchesi, Oliver A. Cornely and Livio Pagano contributed to study design, study supervision, statistical plan, data interpretation and wrote the paper. Jon Salmanton-García performed the analysis. All authors recruited participants and collected and interpreted data, contributed to manuscript writing and review of the manuscript, agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved, and have read and agreed to the published version of the manuscript.

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CONFLICT OF INTEREST STATEMENT

This manuscript was written as part of our routine work. Authors declare no conflict of interest regarding the submitted work.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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REFERENCES

1. Vijenthira A, Gong IY, Fox TA, et al. Outcomes of patients with hematologic malignancies and COVID-19: a systematic review and meta-analysis of 3377 patients. *Blood*. 2020;136(25):2881-2892. https://doi.org/10.1182/blood.2020008824
2. Pagano L, Salmanton-García J, Marchesi F, et al. COVID-19 infection in adult patients with hematological malignancies: a European Hematology Association Survey (EPICOVIDEHA). *J Hematol Oncol*. 2021;14(1):168. https://doi.org/10.1186/s13045-021-01177-0
3. Lee LYW, Cazier JB, Starkey T, et al. COVID-19 prevalence and mortality in patients with cancer and the effect of primary tumour subtype and patient demographics: a prospective cohort study. *Lancet Oncol*. 2020;21(10):1309-1316. https://doi.org/10.1016/s1470-2045(20)30442-3
4. Raje NS, Anaissie E, Kumar SK, et al. Consensus guidelines and recommendations for infection prevention in multiple myeloma: a report from the International Myeloma Working Group. *Lancet Haematol*. 2022;9(2):e143-e161. https://doi.org/10.1016/s2352-3026(21)00283-0
5. Chari A, Samur MK, Martinez-Lopez J, et al. Clinical features associated with COVID-19 outcome in multiple myeloma: first results from the International Myeloma Society data set. *Blood*. 2020;136(26):3033-3040. https://doi.org/10.1182/blood.2020008150
6. Martínez-López J, Mateos MV, Encinas C, et al. Multiple myeloma and SARS-CoV-2 infection: clinical characteristics and prognostic factors of inpatient mortality. *Blood Cancer J*. 2020;10(10):103. https://doi.org/10.1038/s41408-020-00372-5
7. Cook G, John Ashcroft A, Pratt G, et al. Real-world assessment of the clinical impact of symptomatic infection with severe acute respiratory syndrome coronavirus (COVID-19 disease) in patients with multiple myeloma receiving systemic anti-cancer therapy. *Br J Haematol*. 2020;190(2):e83-e86. https://doi.org/10.1111/bjh.16874
8. Ho M, Zanwar S, Buadi FK, et al. Risk factors for severe infection and mortality in patients with COVID-19 in patients with multiple myeloma and AL amyloidosis. *Am J Hematol*. 2023;98(1):49-55. https://doi.org/10.1002/ajh.26762
9. Ludwig H, Sonneveld P, Facon T, et al. COVID-19 vaccination in patients with multiple myeloma: a consensus of the European Myeloma Network. *Lancet Haematol*. 2021;8(12):e934-e946. https://doi.org/10.1016/s2352-3026(21)00278-7
10. Terpos E, Gavriatopoulou M, Ntanasis-Stathopoulos I, et al. The neutralizing antibody response post COVID-19 vaccination in patients with myeloma is highly dependent on the type of anti-myeloma treatment. *Blood Cancer J*. 2021;11(8):138. https://doi.org/10.1038/s41408-021-00530-3
11. Ghandili S, Schonlein M, Wiessner C, et al. Lymphocytopenia and anti-CD38 directed treatment impact the serological SARS-CoV-2 response after prime boost vaccination in patients with multiple myeloma. *J Clin Med*. 2021;10(23):5499. https://doi.org/10.3390/jcm10235499
12. Henriquez S, Zerbit J, Bruel T, et al. Anti-CD38 therapy impairs SARS-CoV-2 vaccine response against alpha and delta variants in patients with multiple myeloma. *Blood*. 2022;139(6):942-946. https://doi.org/10.1182/blood.2021013714
13. Van Oekelen O, Gleason CR, Agte S, 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(8):1028-1030. https://doi.org/10.1016/j.ccell.2021.06.014
14. Nooka AK, Shanmugasundaram U, Cheedarla N, et al. Determinants of neutralizing antibody response after SARS CoV-2 vaccination in patients with myeloma. *J Clin Oncol*. 2022;40(26):3057-3064. https://doi.org/10.1200/jco.21.02257
15. Faustini SE, Hall A, Brown S, et al. Immune responses to COVID-19 booster vaccinations in intensively anti-CD38 antibody treated patients with ultra-high-risk multiple myeloma: results from the Myeloma UK (MUK) nine OPTIMUM trial. *Br J Haematol*. 2023;201(5):845-850. https://doi.org/10.1111/bjh.18714
16. Terpos E, Gavriatopoulou M, Ntanasis-Stathopoulos I, et al. Booster BNT162b2 optimizes SARS-CoV-2 humoral response in patients with myeloma: the negative effect of anti-BCMA therapy. *Blood*. 2022;139(9):1409-1412. https://doi.org/10.1182/blood.2021014989
17. Ntanasis-Stathopoulos I, Karalis V, Gavriatopoulou M, et al. Second booster BNT162b2 restores SARS-CoV-2 humoral response in patients with multiple myeloma, excluding those under anti-BCMA

therapy. *Hemasphere*. 2022;6(8):e764. https://doi.org/10.1097/hs9.0000000000000764
18. Attolico I, Tarantini F, Carluccio P, et al. Serological response following BNT162b2 anti-SARS-CoV-2 mRNA vaccination in haematopoietic stem cell transplantation patients. *Br J Haematol*. 2022;196(4):928-931. https://doi.org/10.1111/bjh.17873
19. Sharma A, Bhatt NS, St Martin A, et al. Clinical characteristics and outcomes of COVID-19 in haematopoietic stem-cell transplantation recipients: an observational cohort study. *Lancet Haematol*. 2021;8(3):e185-e193. https://doi.org/10.1016/s2352-3026(20)30429-4
20. Dhakal B, Abedin S, Fenske T, et al. Response to SARS-CoV-2 vaccination in patients after hematopoietic cell transplantation and CAR T-cell therapy. *Blood*. 2021;138(14):1278-1281. https://doi.org/10.1182/blood.2021012769
21. Salvini M, Maggi F, Damonte C, et al. Immunogenicity of anti-SARS-CoV-2 Comirnaty vaccine in patients with lymphomas and myeloma who underwent autologous stem cell transplantation. *Bone Marrow Transpl*. 2022;57(1):137-139. https://doi.org/10.1038/s41409-021-01487-4
22. Busca A, Salmanton-García J, Marchesi F, et al. Outcome of COVID-19 in allogeneic stem cell transplant recipients: results from the EPICOVIDEHA registry. *Front Immunol*. 2023;14:1125030. PMID: 36911708. https://doi.org/10.3389/fimmu.2023.1125030
23. van Doesum JA, Salmanton-García J, Marchesi F, et al. Impact of SARS-CoV-2 vaccination and monoclonal antibodies on outcome post CD19-CAR-T: an EPICOVIDEHA survey. *Blood Adv*. 2023;7(11):2645-2655. bloodadvances.2022009578 Online ahead of print. PMID: 37058479. https://doi.org/10.1182/bloodadvances.2022009578
24. Pagano L, Salmanton-García J, Marchesi F, et al. Breakthrough COVID-19 in vaccinated patients with hematologic malignancies: results from the EPICOVIDEHA survey. *Blood*. 2022;140(26):2773-2787. https://doi.org/10.1182/blood.2022017257
25. Wang L, Berger NA, Xu R. Risks of SARS-CoV-2 breakthrough infection and hospitalization in fully vaccinated patients with multiple myeloma. *JAMA Netw Open*. 2021;4(11):e2137575. https://doi.org/10.1001/jamanetworkopen.2021.37575
26. Sgherza N, Curci P, Rizzi R, et al. SARS-CoV-2 infection in fully vaccinated patients with multiple myeloma. *Blood Cancer J*. 2021;11(12):201. https://doi.org/10.1038/s41408-021-00597-y
27. Pagano L, Salmanton-García J, Marchesi F, et al. COVID-19 in vaccinated adult patients with hematological malignancies: preliminary results from EPICOVIDEHA. *Blood*. 2022;139(10):1588-1592. https://doi.org/10.1182/blood.2021014124
28. Ocon AJ, Ocon KE, Battaglia J, et al. Real-world effectiveness of tixagevimab and cilgavimab (evusheld) in patients with hematological malignancies. *J Hematol*. 2022;11(6):210-215. https://doi.org/10.14740/jh1062
29. Marchesi F, Salmanton-García J, Buquicchio C, et al. Passive pre-exposure immunization by tixagevimab/cilgavimab in patients with hematological malignancy and COVID-19: matched-paired analysis in the EPICOVIDEHA registry. *J Hematol Oncol*. 2023;16(1):32. https://doi.org/10.1186/s13045-023-01423-7
30. Takashita E, Yamayoshi S, Simon V, et al. Efficacy of antibodies and antiviral drugs against omicron BA.2.12.1, BA.4, and BA.5 subvariants. *N Engl J Med*. 2022;387(5):468-470. https://doi.org/10.1056/nejmc2207519
31. Spiliopoulou V, Ntanasis-Stathopoulos I, Malandrakis P, et al. Use of oral antivirals ritonavir-nirmatrelvir and molnupiravir in patients with multiple myeloma is associated with low rates of severe COVID-19: a single-center, prospective study. *Viruses*. 2023;15(3):704. https://doi.org/10.3390/v15030704
32. Salmanton-García J, Marchesi F, da Gomes Silva M, et al. Nirmatrelvir/ritonavir in COVID-19 patients with haematological malignancies: a report from the EPICOVIDEHA registry. *EClinicalMedicine*. 2023;58:101939. Epub 2023 Apr 6.PMID: 37041967. https://doi.org/10.1016/j.eclinm.2023.101939
33. Terpos E, Engelhardt M, Cook G, et al. Management of patients with multiple myeloma in the era of COVID-19 pandemic: a consensus paper from the European Myeloma Network (EMN). *Leukemia*. 2020;34(8):2000-2011. https://doi.org/10.1038/s41375-020-0876-z
34. Salmanton-García J, Busca A, Cornely OA, et al. EPICOVIDEHA: a ready to use platform for epidemiological studies in hematological patients with COVID-19. *Hemasphere*. 2021;5(7):e612. https://doi.org/10.1097/hs9.0000000000000612
35. Tivian XI GmbH. Experience-management Software. Accessed 28 December 2021. https://www.tivian.com/de/
36. COVID-19 clinical management. Living guidance World Health Organization. 2021. WHO/2019-nCoV/clinical/2021.1.
37. Mourad A, Thibault D, Holland TL, et al. Dexamethasone for inpatients with COVID-19 in a national cohort. *JAMA Netw Open*. 2023;6(4):e238516. https://doi.org/10.1001/jamanetworkopen.2023.8516
38. Horby P, Lim WS, Emberson JR, et al. Dexamethasone in hospitalized patients with Covid-19. *N Engl J Med*. 2021;384(8):693-704. https://doi.org/10.1056/nejmoa2021436
39. Cesaro S, Ljungman P, Mikulska M, et al. Recommendations for the management of COVID-19 in patients with haematological malignancies or haematopoietic cell transplantation, from the 2021 European Conference on Infections in Leukaemia (ECIL 9). *Leukemia*. 2022;36(6):1467-1480. Epub 2022 Apr 29. PMID: 35488021; PMCID: PMC9053562.]. https://doi.org/10.1038/s41375-022-01578-1
40. Chuleerarux N, Manothummetha K, Moonla C, et al. Immunogenicity of SARS-CoV-2 vaccines in patients with multiple myeloma: a systematic review and meta-analysis. *Blood Adv*. 2022;6(24):6198-6207. https://doi.org/10.1182/bloodadvances.2022008530
41. Schiller Salton N, Szwarcwort M, Tzoran I, et al. Attenuated humoral immune response following anti-SARS-CoV-2 vaccine in heavily pretreated patients with multiple myeloma and AL amyloidosis. *Am J Hematol*. 2021;96(12):E475-E478. https://doi.org/10.1002/ajh.26373
42. Goldwater MS, Stampfer SD, Sean Regidor B, et al. Third dose of an mRNA COVID-19 vaccine for patients with multiple myeloma. *Clin Infect Pract*. 2023;17:100214. https://doi.org/10.1016/j.clinpr.2022.100214
43. Aleman A, Van Oekelen O, Upadhyaya B, et al. Augmentation of humoral and cellular immune responses after third-dose SARS-CoV-2 vaccination and viral neutralization in myeloma patients. *Cancer Cell*. 2022;40(5):441-443. https://doi.org/10.1016/j.ccell.2022.03.013
44. Enssle JC, Campe J, Büchel S, et al. Enhanced but variant-dependent serological and cellular immune responses to third-dose BNT162b2 vaccination in patients with multiple myeloma. *Cancer Cell*. 2022;40(6):587-589. https://doi.org/10.1016/j.ccell.2022.05.003
45. Salmanton-García J, Marchesi F, Glenthøj A, et al. Improved clinical outcome of COVID-19 in hematologic malignancy patients receiving a fourth dose of anti-SARS-CoV-2 vaccine: an EPICOVIDEHA report. *Hemasphere*. 2022;6(11):e789. https://doi.org/10.1097/hs9.0000000000000789
46. Blennow O, Salmanton-García J, Nowak P, et al. Outcome of infection with omicron SARS-CoV-2 variant in patients with hematological malignancies: an EPICOVIDEHA survey report. *Am J Hematol*. 2022;97(8):E312-E317. https://doi.org/10.1002/ajh.26626
47. Terpos E, Rajkumar SV, Leung N. Neutralizing antibody testing in patients with multiple myeloma following COVID-19 vaccination. *JAMA Oncol*. 2022;8(2):201-202. https://doi.org/10.1001/jamaoncol.2021.5942

48. Khoury DS, Cromer D, Reynaldi A, et al. Neutralizing antibody levels are highly predictive of immune protection from symptomatic SARS-CoV-2 infection. *Nat Med*. 2021;27(7):1205-1211. https://doi.org/10.1038/s41591-021-01377-8
49. Enßle JC, Campe J, Schwenger A, et al. Severe impairment of T-cell responses to BNT162b2 immunization in patients with multiple myeloma. *Blood*. 2022;139(1):137-142. https://doi.org/10.1182/blood.2021013429
50. Gavriatopoulou M, Terpos E, Malandrakis P, et al. Myeloma patients with COVID-19 have superior antibody responses compared to patients fully vaccinated with the BNT162b2 vaccine. *Br J Haematol*. 2022;196(2):356-359. https://doi.org/10.1111/bjh.17841
51. Pratama NR, Wafa IA, Budi DS, et al. Effectiveness of COVID-19 vaccines against SARS-CoV-2 omicron variant (B.1.1.529): a systematic review with meta-analysis and meta-regression. *Vaccines (Basel)*. 2022;10(12):2180. https://doi.org/10.3390/vaccines10122180
52. Zou J, Kurhade C, Patel S, et al. Neutralization of BA.4-BA.5, BA.4.6, BA.2.75.2, BQ.1.1, and XBB.1 with bivalent vaccine. *N Engl J Med*. 2023;388(9):854-857. https://doi.org/10.1056/nejmc2214916
53. Wang L, Kaelber DC, Xu R, Berger NA. COVID-19 breakthrough infections, hospitalizations and mortality in fully vaccinated patients with hematologic malignancies: a clarion call for maintaining mitigation and ramping-up research. *Blood Rev*. 2022;54:100931. https://doi.org/10.1016/j.blre.2022.100931
54. Terpos E, Musto P, Engelhardt M, et al. Management of patients with multiple myeloma and COVID-19 in the post pandemic era: a consensus paper from the European Myeloma Network (EMN) [published online ahead of print, 2023 May 4]. *Leukemia*. 2023:1-11.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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