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Immunogenicity and safety of the BNT162b2 mRNA COVID-19 vaccine in people living with HIV-1

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ABSTRACT

Objectives: The immunogenicity and safety of the Pfizer-BioNTech BNT162b2 mRNA vaccine in people living with human immunodeficiency virus type 1 (PLWH) are unknown. We aimed to assess the immunogenicity and safety of this vaccine in PLWH.

Methods: In this prospective open study, we enrolled 143 PLWH, aged ≥18 years, who attended our clinic and 261 immunocompetent health-care workers (HCWs). Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) receptor binding domain (RBD) IgG and neutralizing antibodies were measured. Adverse events, viral load and CD4 cell counts were monitored.

Results: At a median of 18 days (interquartile range 14–21 days) after the second dose, anti-RBD-IgG was positive in 139/141 (98%) PLWH. Among HCWs, 258/261 (98.9%) developed anti-RBD-IgG at a median of 26 days (interquartile range 24–27 days) after the second dose. Following the second dose, immune sera neutralized SARS-CoV-2 pseudo-virus in 97% and 98% of PLWH and HCWs, respectively. Adverse events were reported in 60% of PLWH, mainly pain at the injection site, fatigue and headache. AIDS-related adverse events were not reported. Human immunodeficiency virus load increased in 3/143 (2%) patients from <40 copies/mL to ≤100 copies/mL. $CD4^+$ T-cell count decreased from a geometric mean of 700 cells/μL (95% CI 648–757 cells/μL) to 633.8 cells/μL (95% CI 588–683 cells/μL) ($p < 0.01$).

Conclusions: BNT162b2 mRNA vaccine appears immunogenic and safe in PLWH who are on antiretroviral therapy with unsuppressed CD4 count and suppressed viral load. **Itzchak Levy, Clin Microbiol Infect 2021;27:1851**

Introduction

The Pfizer-BioNTech BNT162b2 mRNA vaccine has been tested for safety and efficacy in a multinational randomized placebo-controlled trial with more than 40 000 participants [1]. In that trial, 196 immunologically stable human immunodeficiency virus type 1 (HIV-1) -positive patients were included, but data for the safety and immunogenicity of the vaccine specifically for that patient group have not been published. Indeed, to the best of our knowledge, there are no data available for the response of people living with HIV (PLWH) to mRNA vaccines.

The BNT162b2 mRNA vaccine was introduced in Israel on 19 December 2020, and our programme to vaccinate PLWH started a day later. Since the initiation of the vaccination programme in

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Israel, 60% of the population aged 12 years and above have been vaccinated by the start of September 2021.

In this study, we examined the immunogenicity and safety of the BNT162b2 mRNA vaccine in 143 PLWH.

Materials and methods

The HIV clinic at the Sheba Medical Centre serves about 1500 ambulatory patients. Enrolment into the study was offered to all adult patients (>18 years) who consented to be vaccinated and to participate in the study. Patients who had recovered from SARS-CoV-2 or had active infection at the time of the vaccination (as shown by positive PCR on respiratory swabs or per history) were excluded. Sociodemographic details and clinical and laboratory data regarding HIV status and co-morbidities were extracted from computerized medical records. Controls were 261 immunocompetent health-care workers (HCWs) who were tested for antibody response 2–3 weeks following the second vaccine.

Institutional review board approval was obtained from ethical review boards of the Sheba Medical Centre (7982-20-SMC for PLWH and 8008-20-SMC for immunocompetent HCWs). Written informed consent was obtained from all participants.

Immunogenicity was evaluated with an ELISA that detects IgG antibodies against the receptor-binding domain (RBD) of SARS-CoV-2 [2,3]. Titres $\geq$1.1 were defined as positive. In addition, a SARS-CoV-2 pseudo-virus neutralization assay was performed to detect SARS-CoV-2 neutralizing antibodies (NA) using a green fluorescent protein reporter-based pseudotyped virus with a vesicular stomatitis virus backbone coated with the SARS-CoV-2 spike (S) protein (generously provided by Dr Gert Zimmer of the Institute of Virology and Immunology, Mittelhäusern, Switzerland). Following titration, 100 focus-forming units of pseudo-SARS-CoV-2 were incubated with a twofold serial dilution of heat-inactivated (56°C for 30 min) tested serum. Following incubation, the virus/serum mixture was transferred to Vero E6 cells and incubated for 90 minutes at 37°C. Plates were incubated for 24 hours and 50% plaque reduction titre was calculated by counting green fluorescent foci using a fluorescence microscope (EVOS M5000, Invitrogen, Carlsbad, CA, USA). Sera not capable of reducing viral replication by 50% at a one ot eight dilution or below were considered non-neutralizing.

Viral load of HIV was determined with Cepheid Xpert® HIV-1 Viral Load, where <40 copies/mL is considered undetectable. $CD4^+$ and $CD8^+$ T-cell counts were determined by flow cytometry analysis in peripheral blood.

All clinical adverse events, including local and systemic reactions, were monitored and recorded. Both solicited and unsolicited events were recorded up to 3 weeks after the second injection.

Continuous variables are presented as means and standard deviation or as geometric means and 95% CI. Categorical variables are presented as *n* (%). Differences between groups were assessed using a χ^2 test and a t test, for categorical and continuous data, respectively. Mixed model repeated measures analyses were applied to estimate changes in parameters (CD4, VL, CD4/CD8) at four timepoints: baseline, after the first and second doses and 4 months after the second dose.

The log-transformed values for IgG and NA were analysed as a continuous variable by using multivariate linear regression. A p value of <0.05 was considered statistically significant. Statistical analysis was performed in SAS version 9.4 (SAS Institute, Cary, NC, USA).

The correlation between IgG and NA and CD4 or CD4/CD8 ratio with IgG and NA (log transformed) were analysed using Spearman's correlation by two-tailed parametric *t* test means with 95% CI.

Results

Baseline characteristics

Our cohort included the first 143 PLWH who were vaccinated with the BNT162b2 mRNA vaccine in our clinic between 20 December 2020 and 27 January 2021. The average time between first and second doses was 21 days (range 15–31 days) (Table 1). The control group included 261 immunocompetent HCWs who were checked for antibody response 26 days (24–27 days) after the second vaccine dose. Among PLWH there were more men compared with the control group (91.6% versus 25.3%, p < 0.0001). The majority (80%) being men having sex with men. PLWH were younger than the controls (49.8 ± 11.6 versus 55.8 ± 14.3 years, p < 0.0001). Mean body mass index in PLWH was similar to that in the controls (25.1 ± 3.8 versus 25.6 ± 4.4 kg/m^2, p 0.3027). PLWH had fewer co-morbidities than controls (11.2% versus 39.1%, p < 0.0001). HIV-associated parameters in PLWH are presented in Table 2. Twenty-six (18.2%) had AIDS at HIV diagnosis or later; the average time from HIV diagnosis to vaccination was 13 years. At the time of vaccination, all patients were on antiretroviral therapy (ART), most of them with integrase inhibitor-based therapy. In all, 95% of PLWH had an undetectable viral load, with baseline geometric mean (GM) $CD4^+$ T-cell count of 700 cells/μL (95% CI 648–757 cells/μL). Sixteen (11.2%) patients had co-morbidities, seven had malignancies (four with solid organ malignancy and three with lymphoma) and two patients had kidney transplants.

Compared with the entire HIV population attending the Sheba clinic, the study group was significantly older (49.8 ± 11.5 versus 43.2 ± 12.7 years; p < 0.0001) and included more men (92% versus 81.5%, p < 0.05) and more men having sex with men (80% versus 38%, p < 0.01). People of sub-Saharan African origin were underrepresented (4.2% versus 16% p < 0.01). Nevertheless, the time from HIV diagnosis (12.9 versus 12.5 years), $CD4^+$ T-cell count on diagnosis (GM 443 versus 470 cells/μL), nadir $CD4^+$ T cells (GM 315 versus 340 cells/μL) and baseline $CD4^+$ T cells before vaccination

Table 1
Baseline characteristics of PLWH and controls vaccinated with BNT162b2 mRNA vaccine

Variable	PLWH (n = 143)	Controls (n = 261)	p value
Male/female (% male)	131/12 (91.6)	66/195 (25.3)	<0.0001
Age (years), mean ± SD	49.8 ± 11.6	55.8 ± 14.3	<0.0001
BMI (kg/m^2), mean ± SD	25.1 ± 3.8	25.6 ± 4.4	0.3027
Co-morbidities[a], total *n* (%)	16 (11.2)	102 (39.1)	<0.0001
Days[b] after first vaccination, median (IQR)	15 (14–19)	NA	NA
Days[c] after second vaccination, median (IQR)	18 (14–21)	26 (24–27)	<0.001

Abbreviations: BMI, body mass index; CG1, control group 1; CG2, control group 2; IQR, interquartile range; NA, not available; PLWH, patients living with HIV.

[a] Co-morbidities included hypertension, diabetes mellitus, dyslipidaemia, ischaemic heart disease, chronic obstructive pulmonary disease, kidney disease and liver disease. (Details are presented in Supplementary material, Table S1).

[b] Refers to days between first vaccination and first blood drawn for serological, virological and immunological studies.

[c] Refers to days between second vaccination and second blood drawn for serological, virological and immunological studies.

Table 2
HIV-related variables (n = 143)

Variable	
Caucasians, *n* (%)	137 (95.8%)
Africans, *n* (%)	6 (4.2%)
Time from HIV diagnosis (years), mean (range)	13.2 (0–36)
>15 years since HIV diagnosis, *n* (%)	48 (33.5%)
AIDS on diagnosis, *n* (%)	26 (18.2%)
Nadir CD4$^+$ T cells per μL, mean (range)	345 (2–900)
Nadir CD4$^+$ T cells <100 cells/μL, *n* (%)	14 (9.8%)
Nadir CD4$^+$ T cells <200 cells/μL, *n* (%)	25 (17.5%)
Nadir CD4$^+$/CD8$^+$ ratio, mean (range)	0.46 (0.03–1.24)
Viral load on diagnosis (copies/mL), mean (range)	626, 518 (42–13 million)
Integrase inhibitors, *n* (%)	135 (94.4%)
2DR	27 (18.9%)

Abbreviations: 2DR, two-drug regimen; HIV-1, human immunodeficiency virus type 1.

(GM 700 versus 702 cells/μL) were not significantly different between the two groups.

Immunogenicity following BNT162b2 vaccination

Antibody responses after the second vaccine dose are summarized in Table 3 and Fig. 1. In all, 139/143 (97%) PLWH developed RBD-IgG antibodies at a median of 18 days (interquartile range 14–21 days) after the vaccine with a GM titre of 5.17 (95% CI 4.84–5.53). In the control group, 258/261 (98.9%) developed antibodies after the second dose at a median of 26 days (interquartile range 24–27 days), with a GM titre of 6.1 (95% CI 5.8–6.4). Linear regression analysis, adjusted for age, sex, body mass index, co-morbidities and number of days after vaccination revealed that PLWH developed lower IgG levels than controls (p 0.008) (Table 4).

Of the PLWH, 131/135 (97%) developed NAs after the second dose with a GM titre of 449 versus 482.8 among controls (Table 3). Adjusted linear regression analysis revealed that PLWH developed NA 24% less than controls (Table 4). There was a significant correlation (r = 0.46; 95% CI 0.31–0.59; p < 0.0001) between RBD-IgG antibodies and NAs (Figure S1). Only four patients did not develop NAs, specifically, a 66-year-old man with a kidney transplant treated with mycophenolate, tacrolimus and prednisone, a 58-year-old man on haemodialysis, a 72-year-old man with ischaemic heart disease, and a 64-year-old woman with non-specific arthritis who was treated with colchicine and developed severe coronavirus disease 2019 (COVID-19) 4 weeks after the second dose of the vaccine.

No correlations between CD4 or CD4/CD8 ratio and IgG or neutralization titre were found (all log transformed, by Spearman correlation).

Safety

Local adverse effects were more common following the first vaccine (40.6% versus 25.6%), while systemic adverse effects were more common following the second vaccine (19.5% versus 47.9%) (see Supplementary material, Table S2). The most common local

Table 3
RBD-IgG and neutralizing antibodies following second vaccine dose

Study group	Positive RBD-IgG, *n*/*N* (%)	RBD-IgG GMT (95% CI)	Positive NA/positive RBD-IgG, *n*/*N* (%)	NA[a] GMT (95% CI)
Controls[b]	258/261 (98.9)	6.1 (5.8–6.4)	197/201 (98)	482.8 (410.8–567.5)
HIV-1	139/143 (97.2)	5.2 (4.8–5.5)	131/135 (97)	449.0 (366.6–550.0)

Abbreviations: GMT, geometric mean titre; HIV-1, human immunodeficiency virus type 1; NA, neutralizing antibodies; RBD, receptor-binding domain; Vx, vaccination.
[a] Only samples with neutralizing antibody titres above the cut-off (>8) were included in the analysis for GMT-NA.
[b] Controls, health-care workers without immunosuppression.

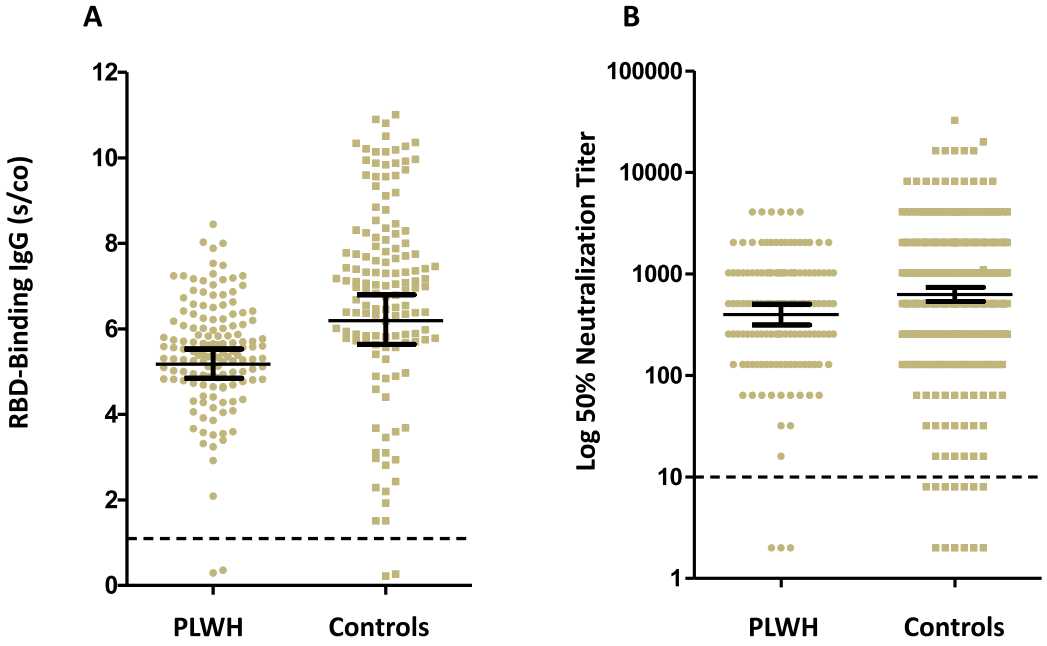

Fig. 1. Quantification of IgG and neutralizing antibodies following the second dose of the BNT162b2 vaccine in people living with human immunodeficiency virus (PLWH) and healthy controls: (a) Receptor-binding domain (RBD) -IgG levels, (b) neutralizing antibodies. Horizontal dotted black lines indicate limit level of positive antibodies. The short black lines indicate geometric mean titre and 95% CI.

Table 4
Multivariate linear regression analysis of predictors of RBD-IgG and neutralizing antibody levels (log transformed) following second vaccination

Variable	Ratio of mean (95% CI)	p value
RBD-IgG predictors[a]		
Male	0.99 (0.84–1.17)	0.95
Age	1.00 (0.99–1.00)	0.35
Body mass index	0.99 (0.97–1.01)	0.25
Days after second vaccine	1.00 (0.99–1.01)	0.80
Co-morbidities	1.01 (0.85–1.19)	0.93
HIV	0.76 (0.62–0.93)	0.008
Neutralizing antibody predictors[b]		
Male	0.76 (0.55–1.06)	0.11
Age	0.98 (0.97–1.00)	0.006
Body mass index	1.04 (1.01–1.08)	0.02
Days after second vaccine	0.96 (0.94–0.99)	0.005
Co-morbidities	0.58 (0.41–0.83)	0.003
HIV	0.67 (0.45–1.01)	0.055

Abbreviations: HIV, human immunodeficiency virus; PLWH, people living with HIV; RBD-IgG, receptor binding domain IgG.
[a] Number of participants 374: 143 PLWH, 261 controls, 30 body mass index missing.
[b] Number of participants 301.

reaction was pain at the injection site (39% and 23.9% after the first and second doses, respectively), which was mild in most cases and subsided within 24 hours. Fatigue and headache were the most common systemic adverse effects after the first dose, whereas fatigue and fever were the most common adverse effects after the second dose. In most cases the fever was <38°C, and fewer than 10% of patients required antipyretics.

HIV-related events following vaccination

None of the participants developed clinical HIV-related events or AIDS-defining conditions following vaccination, with 18 days (interquartile range 14–21 days) of follow up after the second dose.

CD4$^+$ T-cell count and HIV-1 viral load following vaccination

Among the PLWH the GM of the CD4$^+$ T-cell count decreased significantly from a GM of 700 (95% CI 648–757) to a GM of 531 (95% CI 429–657) following the first dose and a GM of 634 (95% CI 588–683) following the second dose (p 0.0089 between baseline and before second vaccine) and GM of 581 (95% CI 523–645) 125 ± 24 days after the second vaccination ($p < 0.0001$ relative to baseline before vaccination). However, the counts remained stable between the first and second doses and 4 months later. This significant drop in CD4 cell count persisted after adjustment for age, sex, origin, body mass index, number of years living with HIV, current or past AIDS, and HIV viral load.

The GM of the CD4$^+$/CD8$^+$ T-cell ratio did not change significantly between baseline, first and second doses and 4 months later GM 0.93 (95% CI 0.85–1.03), GM 0.96 (95% CI 0.78–1.17), GM 0.929 (95% CI 0.84–1.017) and GM 0.85 (95% CI 0.76–0.96), respectively.

In three patients the viral load increased after the second dose from undetectable levels (<40 copies/mL) to 47, 52 and 92 copies/mL. In three patients who had low-level viraemia at baseline, the viral load did not change significantly following vaccination. Four months after vaccination one patient out of 87 (1.15%) blipped to 159 copies/mL, but dropped a week later to 60 copies/mL, no drug resistance mutations were revealed and we continue to follow this patient closely.

All measurements of CD4, CD8 and viral load were done on the same cohort of patients.

Discussion

In our study, the BNT162b2 vaccine was found to be immunogenic and safe in PLWH. However our study population included stable and older HIV-1-positive individuals, mostly with long-standing HIV, treated with integrase inhibitor, and with undetectable viral load and current high CD4$^+$ cell count.

Importantly, although it seems that PLWH may have lower RBD-IgG antibody levels compared with immunocompetent HCWs, 97%–98% of PLWH did develop antibodies after second vaccination and their neutralizing activity was similar to the controls.

Although we still do not know the significance of the small discrepancy between RBD-IgG levels in PLWH relative to controls, most of the PLWH developed neutralizing activity similar to controls, and this serves better as a correlate of immunity than total anti RBD-IgG antibodies [4]. Nevertheless, in our study there was a high correlation between RBD-IgG antibodies and NAs.

For HIV patients, it is important to collect data on immunogenicity because the cell-mediated and B-cell immune abnormalities that occur as HIV infection advances may reduce the magnitude of the response and the durability of the protection. Nonetheless, several studies have demonstrated the protective benefit of vaccinations against influenza virus [5,6] and *Streptococcus pneumoniae* [7,8], even in patients with advanced HIV infections. Although efficacy data are sparse for other types of vaccine, studies using surrogate end points (most commonly post-vaccination antibody levels) have shown that most HIV patients do generate antibody responses post vaccination.

In our cohort, only three patients had a current CD4 count of <200 cells/μL, but all developed high levels of RBD-IgG antibodies and NAs in response to vaccination.

We found a statistically significant decrease in CD4$^+$ T-cell count between baseline levels and those measured following the first and second vaccines, as well as 4 months after the second vaccination. This drop was not associated with any clinical signs or symptoms, but it should be further monitored. It should be noted that the study was conducted among PLWH who were stable on ART with unsuppressed CD4 count and suppressed viral load. A drop in CD4 count may be deleterious for people whose CD4 count is already low, and counts may not recover as rapidly in people who are not stable on ART.

A similar drop in CD4$^+$ T-cell count was not reported in other studies on different types of vaccinations; for example, two studies that examined CD4$^+$ T-cell dynamics in PLWH receiving the heptavalent pneumococcal conjugate vaccine (PCV-7) did not find significant changes in CD4$^+$ count in response to the vaccine at 6 months [9] and 3–4 months [10] post vaccination. In addition, a large study evaluating influenza immunizations in over 30 000 HIV patients found no long-term negative effects on CD4 counts, HIV RNA levels, or progression to AIDS or death [11].

In our study, HIV-1 viral load increased in three individuals from undetectable (<40 copies/mL) to low-level viraemia (<100 copies/ml) immediately after vaccination. These patients had nadir CD4$^+$ counts of <200 cells/μL and also had viral failures, which may imply an increased reservoir. These 'blips' [12] are usually not considered

as viral failure, and are not rare among PLWH, occurring in about one-quarter of patients on stable ART with undetectable viral loads [13]. A transient increase in HIV-1 viral load was also detected 2 weeks following influenza vaccination in well-controlled patients with HIV [14]; that study found a concomitant decrease in proviral DNA and memory phenotype $CD4^+$ cells and claimed that the elevated viral load could suggest mobilization of a latent reservoir.

We found that the BNT162b2 mRNA COVID-19 vaccine was safe. None of the patients developed an immediate or delayed type hypersensitivity reaction. Following the first and second doses, 40.6% and 25.6% developed local reactions, respectively, but in most cases they were mild to moderate and subsided after 24–48 hours. Although safety data were not collected for controls at the time that the study was conducted, the rate of adverse events that we found among PLWH was lower than that reported for the Pfizer phase 2/3 trial, with the difference probably being due to the different way in which adverse events were monitored.

The main limitations of this study include lack of appropriated control, small size and limited follow up.

A matched case–control study in which PLWH were matched to HCWs according to the exposure was not feasible because of differences in age and sex. As the blood in the PLWH and the controls was drawn for serological response at different time-points in windows that do not overlap we have adjusted the groups in multivariable linear regression not only for age, sex and co-morbidities but also for timing of serology from the second vaccine dose. It should be also stated that in former studies age and sex had a limited effect on antibody production [15].

The small size and limited follow up do not enable us to check for efficacy of the vaccine in PLWH.

In conclusion, this prospective study demonstrates the immunogenicity and safety of the BNT162b2 mRNA vaccine in a stable cohort of PLWH with a preserved immune system.

Transparency declaration

We declare that there are no conflicts of interest.

Author contributions

IL, ES, YL and GR were involved in the study design and supervision; IL, AWF, VL, AB, MG, ES, TH and CC were involved in data collection; VI, OM and YL performed the laboratory work and LO and AH performed the data analysis. All the authors were involved in writing the paper and have approved the final version.

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Appendix A. Supplementary data

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References

[1] Polack FP, Thomas SJ, Kitchin N, Absalon J, Gurtman A, Lockhart S, et al. Safety and efficacy of the BNT162b2 mRNA Covid-19 vaccine. N Engl J Med 2020;383:2603–15.
[2] Oved K, Olmer L, Shemer-Avni Y, Wolf T, Supino-Rosin L, Prajgrod G, et al. Multi-center nationwide comparison of seven serology assays reveals a SARS-CoV-2 non-responding seronegative subpopulation. EClinMed 2020;29:100651.
[3] Indenbaum V, Koren R, Katz-Likvornik S, Yitzchaki M, Halpern O, Regev-Yochay G, et al. Testing IgG antibodies against the RBD of SARS-CoV-2 is sufficient and necessary for COVID-19 diagnosis. PLoS One 2020;15:e0241164.
[4] Tasker SA, O'Brien WA, Treanor JJ, Weiss PJ, Olson PE, Kaplan AH, et al. Effects of influenza vaccination in HIV-infected adults: a double-blind, placebo controlled trial. Vaccine 1998;16:1039–42.
[5] Iyer AS, Jones FK, Nodoushani A, Kelly M, Becker M, Slater D, et al. Dynamics and significance of the antibody response to SARS-CoV-2 infection. medRxiv 2020. preprint.
[6] Yamanaka H, Teruya K, Tanaka M, Kikuchi Y, Takahashi T, Kimura S, et al., HIV/Influenza vaccine study team. HIV/Influenza Vaccine Study Team. Efficacy and immunologic responses to influenza vaccine in HIV-1-infected patients. J Acquir Immune Defic Syndr 2005;39:167–73.
[7] Hung CC, Chen MY, Hsieh SM, Hsiao CF, Sheng WH, Chang SC. Clinical experience of the 23-valent capsular polysaccharide pneumococcal vaccination in HIV-1-infected patients receiving highly active antiretroviral therapy: a prospective observational study. Vaccine 2004;22:2006–12.
[8] Grau I, Pallares R, Tubau F, Schulze MH, Llopis F, Podzamczer D, et al. Spanish Pneumococcal Infection Study Network (G03/103). Epidemiologic changes in bacteremic pneumococcal disease in patients with human immunodeficiency virus in the era of highly active antiretroviral therapy. Arch Intern Med 2005;165:1533–40.
[9] Ibraz Pavon AB, French N. No changes on viral load and $CD4^+$ T-cell counts following immunization with 7-valent pneumococcal conjugate vaccine among HIV-infected adults in Malawi. Vaccine 2018;36:2504–6.
[10] Lu CL, Chang SY, Sun HY, Liu WC, Tseng YT, Hsieh CY, et al. Impact of vaccination with seven-valent pneumococcal conjugate vaccine on virologic and immunologic outcomes among HIV-infected adult patients in the era of highly active antiretroviral therapy. J Formos Med Assoc 2012;111:445–51.
[11] Sullivan PS, Hanson DL, Dworkin MS, Jones JL, Ward JW. Adult and Adolescent Spectrum of HIV Disease Investigators. Effect of influenza vaccination on disease progression among HIV-infected persons. AIDS 2000;14:2781–5.
[12] Havlir DV, Bassett R, Levitan D, Gilbert P, Tebas P, Collier AC, et al. Prevalence and predictive value of intermittent viremia with combination HIV therapy. JAMA 2001;286:171–9.
[13] Sklar PA, Ward DJ, Baker RK, Wood KC, Gafoor Z, Alzola CF, et al. Prevalence and clinical correlates of HIV viremia (blips) in patients with previous suppression below the limits of quantification. AIDS 2002;16:2035–41.
[14] Gunthard HF, Wong JK, Spina CA, Ignacio C, Kwok S, Christopherson C, et al. Effect of influenza vaccination on viral replication and immune response in persons infected with human immunodeficiency virus receiving potent antiretroviral therapy. J Infect Dis 2000;181:522–31.
[15] Walsh EE, Frenk Jr RW, Falsey AR, Kitchin N, Absalon J, Gurtman A, et al. Safety and immunogenicity of two RNA based COVID-19 vaccine candidates. N Engl J Med 2020;383:2439–50.