**SARS-CoV-2 vaccination following haematopoietic stem cell transplant (HSCT) and chimeric antigen receptor T-cell (CAR-T) therapy. Prepared by the British Society of Blood and Marrow Transplantation and Cellular Therapy Vaccination Sub-Committee (BSBMT-CT-VSC); updated 26th November 2021**

**National SARS-CoV-2 Vaccination Strategy**

The Joint Committee on Vaccination and Immunisation (JCVI) advised a phased approach to vaccination in the UK. In phase 1, the JCVI identified 9 priority groups determined by age, exposure risk and comorbidities. Clinically extremely vulnerable (CEV) individuals were included in group 4 and individuals with underlying health conditions in group 6, with individuals vaccinated according to their highest risk group. Group 4 includes people with cancers of the blood or bone marrow who are at any stage of treatment, and people who have had bone marrow or stem cell transplants in the last 6 months or who are still taking immunosuppressive therapy (IST). Group 6 includes bone marrow and stem cell transplant recipients who are not captured in group 4. In March 2021 the JCVI recommended that those aged over 16 who are household contacts of immunosuppressed adults should also be offered vaccination in group 6.[1]

On 01 September 2021, the JCVI recommended 3rd primary doses for certain immunosuppressed groups, including individuals who have received an autologous or allogeneic HSCT within the last 24 months, or had ongoing immunosuppression or graft versus host disease (GvHD) at the time of their 1st or 2nd vaccine dose,[2] regardless of time from transplant. This recommendation was soon followed by guidance offering a booster dose to other groups who had a 2-dose primary course, including those aged over 16 who live with someone who is more likely to get infections. It is expected that immunosuppressed groups receiving 3rd primary doses in the autumn of 2021 will become eligible for a 4th booster dose approximately 6 months after the 3rd primary dose.

Children aged 12 to 17 with immunosuppressive conditions (including HSCT recipients) are now eligible for 3 primary doses of SARS-CoV-2 vaccines in line with recommendations for adults aged 18 and over. Children aged 12 to 15 living with individuals at high risk of infection are also eligible for a 2-dose primary course.

**SARS-CoV-2 Vaccines**

Currently, four SARS-CoV-2 vaccines are licensed for use in the UK, three of which are being used as part of the NHS vaccine roll-out. All three of these vaccines induce immune responses to the spike component of SARS-CoV-2. None of these studies have included HSCT or CAR-T recipients.

On 2 December 2020, the Medicines and Healthcare products Regulatory Agency (MHRA) approved use of the Pfizer/BioNTech SARS-Cov-2 vaccine (BNT162b2) in the UK. BNT162b2 is a first-in-class mRNA vaccine. In a phase 3 study, BNT162b2 was administered to participants aged 16 or over in a 2-dose regimen[3]. The vaccine was 95% efficacious against symptomatic COVID-19 from 7 days after the 2nd dose. Included in this analysis were those patients who had received the 2nd dose within the pre-defined window of 19-42 days following the first. In the interval between the first and second dose, vaccine efficacy was 52%, although the authors acknowledge the study was not designed to assess a single-dose regimen. Most cases were within the first 10 days after vaccination, and efficacy between days 15-21 may be higher[4,5]. Efficacy was consistent across age, gender and ethnicity, and no serious safety concerns were reported. The dataset included 76 patients with leukaemia and lymphoma who responded with similar efficacy (though detailed information about these patients was not included in the safety pack). A real-world study of BNT162b2 in staff of UK NHS hospitals showed vaccine effectiveness of 70% 21 days after the first dose, and 85% 7 days after 2 doses.[6]

The AstraZeneca chimpanzee adenoviral vector ChAdOx1 nCOV-19 vaccine was approved for use by the MHRA on 30 December 2020. Across four studies participants received a 2-dose regimen at a range of 4-26 weeks. In a pooled analysis overall vaccine efficacy was 70.4% with confidence in the estimate up to 12 weeks. From 22 days post dose 1, vaccine efficacy was 73.4% with analysis censored at 12 weeks or from administration of dose 2. A longer interval between first and second dose was associated with increased immunogenicity. Vaccine efficacy in participants aged over 55 was not assessed[7] although similar immunogenicity across a range of ages is reported. Again, no serious safety concerns were reported. In a post-hoc exploratory analysis, efficacy of a single dose against symptomatic COVID-19 was 76% from days 22-90. A longer dosing interval was associated with greater efficacy post-second dose; with a dosing interval of <6 weeks efficacy was 54.9%, and at ≥12 weeks it was 80.7%.[8]

The Moderna mRNA SARS-CoV-2 vaccine (mRNA-1273) was approved for use by the MHRA on 8 January 2021. In a phase 3 study overall vaccine efficacy was 94.1% for prevention of symptomatic COVID-19, with 98% of participants receiving the 2nd dose of vaccine within the predefined period of 25-35 days.[9] In the placebo group there were 30 cases of severe COVID-19 and none in the vaccine group. Vaccine efficacy was consistent across age (18 to <65, and >65 years of age), sex, and ethnic groups. There were no major safety signals.

Emerging data suggest that transmission rates can be reduced by vaccination. PCR positivity (asymptomatic and symptomatic) was reduced by 67% after a single standard dose of the ChAdOx1 nCOV-19, and by 49.5% after 2 standard doses suggesting the potential for an impact on transmission.[7] Pre-print data from Public Health England demonstrates that following vaccination with ChAdOx1 nCOV-19 and BNT162b2, there is a 40-50% reduction in household transmission from individuals who are subsequently infected with COVID-19.[10] However, there may be less impact on transmission of new variants (such as Delta).[11]

**Vaccine Induced Thrombosis and Thrombocytopenia (VITT)**

A rare syndrome of thrombosis and thrombocytopenia with high levels of d-dimers, low levels of fibrinogen, and with platelet factor 4 (PF4) antibodies detectable by enzyme-linked immunosorbent assay (ELISA) has been described between 5-28 days after administration of the first dose of ChAdOx1 nCOV-19 vaccine.[12–14] This appears to be an idiosyncratic reaction to the first dose of the AstraZeneca vaccine and no risk factors have been identified. The JCVI has recommended that adults under 40 years of age who are not in a clinical priority group should be offered an alternative to the Astra Zeneca vaccine where possible, but that the benefits outweigh the risks in CEV groups under 40 years. Therefore CEV patients including HSCT and CAR-T recipients may be offered vaccination with any of the available products, including the AstraZeneca vaccine, for the first two vaccine doses providing there are no other contraindications. There are no specific recommendations for post-vaccination laboratory monitoring.

**SARS-CoV-2 Vaccine Scheduling**

The following scheduling is recommended in the UK Green Book for the first two vaccine doses[5]:-

- Pfizer mRNA BNT162b2 Vaccine. 2 doses 3-12 weeks apart in individuals ≥12 years of age
- AstraZeneca ChAdOX1-S Vaccine. 2 doses 4-12 weeks apart in individuals ≥18 years of age
- Moderna mRNA-1273 Vaccine. 2 doses a minimum of 28 days apart in individuals ≥12 years of age

Due to evidence that immunogenicity and/or vaccine efficacy is higher with both the adenovirus vector and mRNA vaccines given with longer intervals between doses, the JCVI recommends a minimum 8-week interval between the first two doses. Administration of the Astra Zeneca vaccine on a 12-week schedule is in keeping with phase 3 and post-hoc exploratory data.[8,15-17] Available efficacy data for the Pfizer vaccine is based on the administration of a second dose within a limited window of 19-42 days. Immunogenicity data in UK healthcare workers show that extended dosing regimens (average 10 weeks) for the Pfizer vaccine results in greater humoral immunogenicity than the short 3-week interval.[16]

**Re-vaccination Schedules in in HSCT Recipients**

After HSCT, a decline in antibody titres to vaccine preventable diseases is apparent within weeks and may continue for years post-HSCT[18-27]. International groups therefore recommend that HSCT recipients are considered never-vaccinated and offered a full re-vaccination schedule.[28-30] Vaccine efficacy studies in HSCT recipients are lacking, and schedules are based largely on immunogenicity data. Although responses against other vaccines are generally lower than in immunocompetent individuals, pneumococcal conjugate vaccines may be immunogenic from as early as 3 months post-HSCT[31] and some other vaccines from 6 months[32,33]. International guidelines recommend re-vaccination schedules are commenced from 3-6 months post-HSCT time-point[29.30]. Data describing the impact of GvHD on vaccine immunogenicity are conflicting, and most international groups advocate vaccination regardless of GvHD, and any therapy required for this condition. UK post-HSCT vaccination practice varies considerably for both paediatric and adult HSCT recipients in both autologous and allogeneic settings[34,35].

**SARS-CoV-2 Vaccination in HSCT Recipients**

HSCT and CAR-T recipients are in a COVID-19 high-risk group and conferring immunity by vaccination at the earliest effective timepoint is desirable. There are emerging data on the immunogenicity of SARS-CoV-2 vaccines in HSCT recipients, mostly to the Pfizer mRNA BNT162b2 vaccine. Seroconversion following two doses of Pfizer vaccine has been shown to occur in 50 – 84.7% of allogeneic HSCT recipients and 60 – 84% of autologous HSCT recipients,[36-40] which was significantly lower than in healthy control participants when included.[38] Similar antibody titres between autologous and allogeneic HSCT recipients have been noted.[41] Several studies have also observed lower antibody induction in individuals within the first 12 months following HSCT.[37,38,41] Data from vaccinated CAR-T therapy recipients are limited, but there are indications that immunogenicity may be lower than in HSCT recipients.[36,38,39] There are currently no published data comprehensively comparing the immunogenicity of the AstraZeneca ChAdOX1-S Vaccine and mRNA vaccines in HSCT or CAR-T recipients. One published study to date has reported on the immunogenicity of a 3rd primary Pfizer vaccine dose in HSCT recipients, with 42% of prior non-responders achieving an antibody titre above a pre-defined antibody threshold predictive of neutralising activity.[42] It is hoped that the UK OCTAVE and OCTAVE-DUO studies will provide further data to help refine vaccine recommendations.

**Pragmatic Vaccination Statements in Absence of a Complete Evidence Base**

In the absence of data to guide optimum vaccination strategies in HSCT recipients, pragmatic recommendations are required now. Vaccination at too early a time-point may be poorly immunogenic, while late vaccination may leave HSCT and CAR-T recipients at unnecessary risk for a prolonged period.

A national expert group on behalf of BSBMTCT has prepared the following statements. The group draws on expertise in adult and paediatric bone marrow transplant, CAR-T therapy, infectious diseases, vaccinology and immunology. The limitations of these statements are acknowledged, but they offer a pragmatic starting position in the absence of clinical evidence in this patient population. These statements are focussed on potentially offering some degree of protection to a very high-risk population in the context of a global pandemic.

Taking into consideration evidence for established vaccines and expert opinion from this group, the following recommendations are proposed:

*Vaccination before HSCT and CAR-T*

- For patients who have not received any SARS-CoV-2 vaccines and have an HSCT or CAR-T procedure scheduled in the immediate future (i.e. weeks to a month), an assessment of risk should inform whether SARS-CoV-2 vaccination is offered pre or post-procedure. Where vaccination is offered pre-procedure, it is preferable to complete the 2-dose schedule prior to conditioning, and second doses may be offered at less than the 8-week interval (but adhering to minimum licensed intervals) if this would allow completion of the course prior to the procedure, in keeping with Green Book guidance.[5]
- In patients who have received prior SARS-CoV-2 vaccines and a future HSCT or CAR-T procedure is planned, the next scheduled dose according to disease-specific and national guidance should be offered prior to the procedure, adhering to the minimum recommended intervals between doses in the Green Book.[5]

*Vaccination after HSCT or CAR-T*

- HSCT and CAR-T recipients who have received a SARS-CoV-2 vaccine pre-procedure should be considered never-vaccinated in keeping with updated May 2021 Green Book guidance[5], and offered re-vaccination with a 3-dose primary course in accordance with the following statements.
- HSCT and CAR-T patients ≥18 years can receive any of the SARS-CoV-2 vaccines currently licensed in the UK and should be encouraged to accept the first vaccine they are offered. A preference for a vaccine type for the re-vaccination course in adults ≥18 years may emerge from ongoing studies, but at present there are insufficient data for a strong recommendation for the first 2 doses. The 3rd primary dose should be an mRNA vaccine in line with Green Book guidance.[5]
- Children 12 – 17 years old should receive a 3-dose primary course with an mRNA vaccine in keeping with current licensure and Green Book guidance, with a preference for the Pfizer BNT162b2 Vaccine due to a reported lower rate of myocarditis.[5] The Moderna mRNA 1273 vaccine is also approved in children.
- Consider vaccination with a SARS-CoV-2 vaccine from 3-6 months post autologous and allogeneic HSCT in individuals aged ≥12 years.

- Consider vaccination with a SARS-CoV-2 vaccine from 3-6 months following CAR-T therapy in individuals aged ≥12 years.

- **Dosing regimen**:
    - Timing of 2nd dose*:* Despite data in healthy adults demonstrating the benefit of extended dosing intervals, the immunogenicity of the first SARS-CoV-2 vaccine dose can be poor in allogeneic HSCT recipients and the first dose vaccine effectiveness against the B.1.617.2/delta variant is reduced, even in the general population.[43,44] Until further data are available to guide scheduling of re-vaccination the BSBMTCT-VSC favours administration of the 2nd dose in HSCT and CAR-T recipients after the minimum licensed interval. i.e. a 3 week interval for Pfizer BNT162b2 and 4 week interval for AstraZeneca ChAdOX1-S and Moderna mRNA 1273 vaccines.
    - A 3rd primary dose should be offered with a SARS-CoV-2 mRNA vaccine at a minimum interval of 8 weeks following the 2nd dose according to Green Book guidance.[5]
    - It is likely that a 4th booster dose approximately 6 months after the 3rd primary dose will be recommended in the national schedule.

- For allogeneic HSCT recipients who are receiving immunosuppressive therapy (IST) consider indication, intensity and expected duration of IST when deciding whether to vaccinate or defer. When patients are approaching the end of an IST weaning schedule a short deferral may be reasonable.
- Consider vaccination of patients with chronic GvHD. Consider intensity and expected duration of GvHD targeted therapy when deciding whether to vaccinate or defer.
- If there is reasonable concern that a short deferral for a clinical reason may in practice result in a longer delay due to vaccine administration issues (e.g. appointment availability, regional shortage etc) then vaccination is suggested over deferral.
- Government shielding guidance has now come to an end. However, HSCT and CAR-T patients should be advised to continue being cautious in their contacts even after receiving a 3-dose primary course as vaccine immunogenicity and efficacy in these patients is at present not fully defined.
- Available vaccines are not currently licensed for use in the under 12-year age group.

*Vaccination of Household Members*

- Adult household members (aged 16 or over) of HSCT and CAR-T recipients should be offered vaccination in accordance with JCVI recommendations, with a 2-dose primary course and further booster dose at least 6 months following the 2nd dose. Children aged 12 – 15 living with HSCT or CAR-T recipients should be offered vaccination with a 2-dose primary course of an mRNA vaccine.

*Donor Vaccination*

Guidelines for vaccination of stem cell donors are available from the Joint United Kingdom Blood Transfusion and Tissue Transplantation Services Professional Advisory Committee (JPAC)

**Knowledge gaps and future research needs**

Unanswered questions include:

1) What immune responses (and thresholds) are associated with protection against COVID-19 and are these different in HSCT/CART recipients compared to immunocompetent individuals?
2) What is the earliest time-point post-HSCT that SARS-CoV-2 vaccines are immunogenic?
3) At what time point post-HSCT is the SARS-CoV-2 vaccine maximally immunogenic and is this comparable to the response in immunocompetent individuals?
4) Does the immune response decay at a similar rate to immunocompetent individuals?
5) Which of the emerging SARS-CoV-2 vaccines (or combination of vaccines) are more immunogenic in HSCT recipients? Is there a role for heterologous vaccination in this specific group?
6) What is the optimal schedule (including dosing interval as well as number of doses) of SARS-CoV-2 vaccines in this population?
7) What is the impact on immunogenicity of patient, donor and transplant variables?
8) What is the safety of vaccines post HSCT, including whether immune related complications such as GVHD or autoimmunity may be triggered by vaccination?

These aspects need to be considered separately for

- Autologous HSCT
- Allogeneic HSCT, where there is an impact of
    a. GvHD and GvHD prophylaxis and therapy
    b. Types of allogeneic HSCT, with varying degrees of HLA mismatch
    c. Unpredictable recovery of immune function
- CAR-T and other cellular therapies
- Paediatric HSCT recipients
- Other aspects such as use of serotherapy before, during and after HSCT (ATG, alemtuzumab, rituximab, daratumumab and other monoclonals)

In addition, there is a need to consider the administration of SARS-CoV-2 vaccination in:

- Healthy donors

Future studies at national and international level should seek to address these questions urgently. In the future case-by-case assessment of immune response to SARS-Cov-2 vaccines as part of clinical practice may help to inform decisions around administration of booster dosing as vaccine supply allows. However, this is not currently recommended as the correlates of protection for SARS-CoV-2 are not yet fully defined. There is also an urgent need for standardised assays of both humoral and cellular immunity to SARS-CoV-2. These remain research tools at present, until immune correlates of protection are established.

These statements will be regularly reviewed and updated as appropriate when further data emerge.

Correspondence update November 2021

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**References**


1. JCVI recommends that adults living with adults who are immunosuppressed should be prioritised for the COVID-19 vaccine. n.d.https://phe-newsroom.prgloo.com/news/jcvi-recommends-that-adults-living-with-adults-who-are-immunosuppressed-should-be-prioritised-for-the-covid-19-vaccine (accessed 18 May2021).

2. https://www.gov.uk/government/publications/third-primary-covid-19-vaccine-dose-for-people-who-are-immunosuppressed-jcvi-advice/joint-committee-on-vaccination-and-immunisation-jcvi-advice-on-third-primary-dose-vaccination

3. Polack FP, Thomas SJ, Kitchin N, Absalon J, Gurtman A, Lockhart S *et al.* Safety and Efficacy of the BNT162b2 mRNA Covid-19 Vaccine. *New Engl J Med* 2020; : 1--13.

4. Pfizer-BioNTech COVID-19 vaccine (BNT162, PF-07302048) vaccines and related biological products advisory committee briefing document. Pfizer-BioBTech, n.d.

5. Green Book Chapter 14a: COVID-19 - SARS-Cov-2. UKHSA, 2021.

6. Hall VJ, Foulkes S, Saei A, Andrews N, Oguti B, Charlett A *et al.* COVID-19 vaccine coverage in health-care workers in England and effectiveness of BNT162b2 mRNA vaccine against infection (SIREN): a prospective, multicentre, cohort study. *Lancet* 2021; **397**: 1725–1735.

7. Voysey M, Clemens SAC, Madhi SA, Weckx LY, Folegatti PM, Aley PK *et al.* Safety and efficacy of the ChAdOx1 nCoV-19 vaccine (AZD1222) against SARS-CoV-2: an interim analysis of four randomised controlled trials in Brazil, South Africa, and the UK. *Lancet* 2020. doi:10.1016/s0140-6736(20)32661-1.

8. Voysey M, Clemens SAC, Madhi SA, Weckx LY, Folegatti PM, Aley PK *et al.* Single-dose administration and the influence of the timing of the booster dose on immunogenicity and efficacy of ChAdOx1 nCoV-19 (AZD1222) vaccine: a pooled analysis of four randomised trials. *Lancet* 2021; **397**: 881–891.

9. Baden LR, El Sahly HME, Essink B, Kotloff K, Frey S, Novak R *et al.* Efficacy and Safety of the mRNA-1273 SARS-CoV-2 Vaccine. *New Engl J Med* 2021; 384:403-416.

10. Harris RJ, Hall JA, Zaidi A, Andrews NJ, Dunbar JK, Dabrera G. Effect of vaccination on household transmission of SARS-COV-2 in England. 2021. *New Engl J Med* 2021; 385:759-760.

11. Singanayagam A, Hakki S, Dunning J, Madon KJ, Crone MA, Koycheva A *et al.* Community transmission and viral load kinetics of the SARS-CoV-2 delta (B.1.617.2) variant in vaccinated and unvaccinated individuals in the UK: a prospective, longitudinal, cohort study. *The Lancet Infectious Diseases* 2021. OI:https://doi.org/10.1016/S1473-3099(21)00648-4

12 Scully M, Singh D, Lown R, Poles A, Solomon T, Levi M *et al.* Pathologic Antibodies to Platelet Factor 4 after ChAdOx1 nCoV-19 Vaccination. *New Engl J Med* 2021. doi:10.1056/nejmoa2105385.

13 Schultz NH, Sørvoll IH, Michelsen AE, Munthe LA, Lund-Johansen F, Ahlen MT *et al.* Thrombosis and Thrombocytopenia after ChAdOx1 nCoV-19 Vaccination. *New Engl J Med* 2021. doi:10.1056/nejmoa2104882.

14 Greinacher A, Thiele T, Warkentin TE, Weisser K, Kyrle PA, Eichinger S. Thrombotic Thrombocytopenia after ChAdOx1 nCov-19 Vaccination. *New Engl J Med* 2021. doi:10.1056/nejmoa2104840.

15 Statement from the UK Chief Medical Officers on the prioritisation of first doses of COVID-19 vaccines | Department of Health. n.d.https://www.health-ni.gov.uk/news/statement-uk-chief-medical-officers-prioritisation-first-doses-covid-19-vaccines (accessed 17 May2021).

16. Payne RP, Longet S, Austin JA, Skelly DT, Dejnirattisai W, Adele S *et al.* Immunogenicity of standard and extended dosing intervals of BNT162b2 mRNA vaccine. *Cell* 2021; 184 (23): P5699-5714.

17. Amirthalingam G, Bernal JL, Andrews NJ, Whitaker H, Gower C, Stowe J *et al.* Higher serological responses and increased vaccine effectiveness demonstrate the value of extended vaccine schedules in combatting COVID-19 in England. *MedRxiv* 2021. Doi: https://doi.org/10.1101/2021.07.26.21261140

18. Patel SR, Ortín M, Cohen BJ, Borrow R, Irving D, Sheldon J, Heath PT. Re-immunization with measles, tetanus, poliovirus, *Haemophilus influenzae* type b, meningococcal C and pneumococcal vaccines in children following hematopoietic stem cell transplantation. Clin Infect Disease 2007;44(5):625-634

19. Ljungman P, Lewensohn-fuchs I, Hammarstrom V, Aschan J, Brandt L, Bolme P *et al.* Long-term immunity to measles, mumps, and rubella after allogeneic bone marrow transplantation. *Blood* 1994; **84**: 657--63.

20. Pauksen K, Duraj V, Ljungman P, Sjolin J, Oberg G, Lonnerholm G *et al.* Immunity to and immunization against measles, rubella and mumps in patients after autologous bone marrow transplantation. *Bone Marrow Transpl* 1992; **9**: 427--32.

21. Ljungman P, Fridell E, Lonnqvist B, Bolme P, Bottiger M, Gahrton G *et al.* Efficacy and safety of vaccination of marrow transplant recipients with a live attenuated measles, mumps, and rubella vaccine. *J Infect Dis* 1989; **159**: 610--615.

22. Ljungman P, Wiklund-Hammarsten M, Duraj V, Hammarstrom L, Lonnqvist B, Paulin T *et al.* Response to tetanus toxoid immunization after allogeneic bone marrow transplantation. *J Infect Dis* 1990; **162**: 496--500.

23. Ljungman P, Duraj V, Magnius L. Response to immunization against polio after allogeneic marrow transplantation. *Bone Marrow Transpl* 1991; **7**: 89--93.

24. Engelhard D, Handsher R, Naparstek E, Hardan I, Strauss N, Aker M *et al.* Immune response to polio vaccination in bone marrow transplant recipients. *Bone Marrow Transpl* 1991; **8**: 295--300.

25. Parkkali T, Stenvik M, Ruutu T, Hovi T, Volin L, Ruutu P. Randomized comparison of early and late vaccination with inactivated poliovirus vaccine after allogeneic BMT. *Bone Marrow Transpl* 1997; **20**: 663--8.

26. Winston DJ, Ho WG, Schiffman G, Champlin RE, Feig SA, Gale RP. Pneumococcal vaccination of recipients of bone marrow transplants. *Arch Intern Med* 1983; **143**: 1735--7.

27. Giebink GS, Warkentin PI, Ramsay NK, Kersey JH. Titers of antibody to pneumococci in allogeneic bone marrow transplant recipients before and after vaccination with pneumococcal vaccine. *J Infect Dis* 1986; **154**: 590--596.

28. Einsele H, Gress R, Sepkowitz K, Storek J, Wingard JR. Guidelines for Preventing Infectious Complications among Haematopoietic Cell Transplant Recipients : A Global Perspective. 2009; **15**: 1143--1238.

29. Rubin LG, Levin MJ, Ljungman P, Davies EG, Avery R, Tomblyn M *et al.* 2013 IDSA clinical practice guideline for vaccination of the immunocompromised host. *Clin Infect Dis* 2014; **58**: 1--57.

30. Cordonnier C, Einarsdottir S, Cesaro S, Blasi RD, Mikulska M, Rieger C *et al.* Vaccination of haemopoietic stem cell transplant recipients: guidelines of the 2017 European Conference on Infections in Leukaemia (ECIL 7). *Lancet Infect Dis* 2019; **19**: e200--e212.

31. Cordonnier C, Labopin M, Chesnel V, Ribaud P, Camara RDL, Martino R *et al.* Randomized study of early versus late immunization with pneumococcal conjugate vaccine after allogeneic stem cell transplantation. *Clin Infect Dis* 2009; **48**: 1392--1401.

32. Parkkali T, Olander RM, Ruutu T, Vuontela K, Volin L, Eskola J *et al.* A randomized comparison between early and late vaccination with tetanus toxoid vaccine after allogeneic BMT. *Bone Marrow Transpl* 1997; **19**: 933--938.

33. Parkkali T, Kayhty H, Anttila M, Ruutu T, Wuorimaa T, Soininen a *et al.* IgG subclasses and avidity of antibodies to polysaccharide antigens in allogeneic BMT recipients after vaccination with pneumococcal polysaccharide and Haemophilus influenzae type b conjugate vaccines. *Bone Marrow Transpl* 1999; **24**: 671--678.

34. Miller PDE, Silva TI de, Skinner R, Gilleece M, Peniket A, Hamblin A *et al.* Routine vaccination practice after adult and paediatric allogeneic haematopoietic stem cell transplant: a survey of UK NHS programmes. *Bone Marrow Transpl* 2017; **52**: 775--777.

35. Gilleece M, Towlson K, Wilson M, Littlewood T, Cook G, Marks D. Vaccination against Infection after Haematopoietic Stem Cell Transplant : A Survey of Practice in the UK and Ireland. *BBMT* 2007; **21**: S614--S708.

36. Dhakal B, Abedin S, Fenske T, Chhabra S, Ledeboer N, Parameswaran H & Hamadani M. Response to SARS-CoV-2 vaccination in patients after haematopoietic cell transplantation and CAR T-cell therapy. *Blood* 2021; 138(14):1278-1281.

37. Redjoul R, Le Bouter A, Beckerich F, Fourati S & Maury S. Antibody response after second BNT162b2 dose in allogeneic HSCT recipients. *Lancet* 2021; 398(10297):298-299.

38. Bergman P, Blennow O, Hansson L, Mielke S, Nowak P, Chen P *et al.* Safety and efficacy of the mRNA BNT162b2 vaccine against SARS-CoV-2 in five groups of immunosuppressed patients and healthy controls in a prospective open-label clinical trial. *MedRxiv* 2021; doi: https://doi.org/10.1101/2021.09.07.21263206

39. Ram R, Hagin D, Kikozashvilli N, Freund T, Amit O, Bar-On Y *et al.* Safety and immunogenicity of the BNT162b2 mRNA COVID-19 vaccine in patients after allogeneic HCT or CD19-based CART therapy – a single-centre prospective cohort study. *Transplantation and Cellular Therapy* 2021; 27(9): 788-794.

40. Chiarucci M, Paolasini S, Isidori A, Guiducci B, Loscocco F, Capalbo M & Visani G. Immunological response against SARS-CoV-2 after BNT162b2 vaccine administration is impaired in allogeneic but not in autologous stem cell transplant recipients. *Front Oncol* 2021; 11:737300

41. 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 study. *Lancet Haematol* 2021; 8(8):e583-e582.

42. 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;8(10):e681-e683.

43. Easdale S, Shea R, Ellis L, Bazin J, Davis K, Dallas F *et al.* Serologic responses following a single dose of SARS-CoV-2 vaccination in allogeneic stem cell transplantation recipients. *Transplantation and Cellular Therapy* 2021;27(10):e880.e1-880.e4

44. Bernal JL, Andrews N, Gower C, Gallagher E, Simmons R, Thelwall S *et al.* Effectiveness of COVID-19 vaccines against the B.1.617.2 (Delta) variant. *New Engl J Med* 2021; 385:585-594