Tidsskriftet Tidsskrift for Den norske legeforening

Vaccination of immunosuppressed patients

CLINICAL REVIEW

MARTON KÖNIG

makoni@ous-hf.no
Department of Neurology
Oslo University Hospital
and
University of Oslo

Author contribution: concept, structure/design, data collection, literature search, drafting/revision of the manuscript and approval of the submitted version
Marton König, senior consultant, senior researcher and lecturer
The author has completed the ICMJE form and declares the following conflicts of interest: he has received research funding from South-Eastern Norway Regional Health Authority, the DAM Foundation, Horizon Europe and the Coalition for Epidemic Preparedness Innovations (CEPI). He has served on advisory boards for Merck (manufacturer of cladribine) and Biogen (natalizumab) and has received speaker fees from Merck (cladribine), Biogen (natalizumab), Novartis (fingolimod, ofatumumab, ciclosporin, secukinumab and canakinumab), Roche (ocrelizumab and rituximab), Sanofi (alemtuzumab) and the Multiple Sclerosis Association in Norway. Merck manufactures HPV and polio vaccines, and Sanofi manufactures influenza and polio vaccines. None of the aforementioned collaborations are related to vaccines, immunisation programmes or medications discussed in this article. Biogen, Novartis and Roche do not produce commercial vaccines.

TRYGVE HOLMØY

Department of Neurology
Akershus University Hospital
and
University of Oslo

Author contribution: design, drafting and revision of the manuscript, and approval of the submitted version
Trygve Holmøy, senior consultant and professor
The author has completed the ICMJE form and declares the following conflicts of interest: he has received consultant fees from Sandoz (manufacturer of natalizumab) and Merck (cladribine) and speaker fees from Merck (cladribine), Biogen (natalizumab), Alexion (ravulizumab and ekulizumab), Novartis (ofatumumab, fingolimod, ciclosporin, secukinumab and canakinumab), Roche (ocrelizumab and rituximab), Amgen (inebilizumab, ekulizumab and adalimumab) and the Multiple Sclerosis Association in Norway. Merck manufactures HPV and polio vaccines. None of the aforementioned collaborations are related to vaccines, immunisation programmes or medications discussed in this article. Biogen, Novartis, Roche, Alexion, Amgen and Sandoz do not produce commercial vaccines.

GRO OWREN NYGAARD

Department of Neurology
Oslo University Hospital
and
University of Oslo
Author contribution: design, drafting and revision of the manuscript, and approval of the submitted version
Gro Owren Nygaard, senior consultant and senior researcher
The author has completed the ICMJE form and declares the following conflicts of interest: she has received research funding from South-Eastern Norway Regional Health Authority, the DAM Foundation, Horizon Europe, the Multiple Sclerosis Association in Norway, Oslo MS Association, the Coalition for Epidemic Preparedness Innovations (CEPI) and Odd Fellows research fund for MS. She has served on the advisory board for Sandoz (manufacturer of natalizumab biosimilar medication, adalimumab and tacrolimus), without receiving any personal fees. Sandoz does not produce commercial vaccines. This collaboration was not related to vaccines, immunisation programmes or medications discussed in this article.

JON RIISE

Department of Oncology
Oslo University Hospital
Author contribution: design, drafting and revision of the manuscript, and approval of the submitted version
Jon Riise, senior consultant and head of department

The author has completed the ICMJE form and declares the following conflicts of interest: he has received research funding from the Coalition for Epidemic Preparedness Innovations (CEPI), served on advisory boards for Roche (manufacturer of ocrelizumab and rituximab), AstraZeneca (tixagevimab/cilgavimab) and Johnson & Johnson (ibrutinib), and has received speaker fees from Johnson & Johnson (ibrutinib) and AstraZeneca (tixagevimab/cilgavimab, which was used for a short period as prophylactic treatment for COVID-19). AstraZeneca and Johnson & Johnson manufacture vaccines, including adenovirus vector-based COVID-19 vaccines. Beyond this, none of the aforementioned collaborations are related to vaccines, immunisation programmes or medications discussed in this article. Roche does not produce commercial vaccines.

KARSTEN MIDTVEDT

Department of Transplantation Medicine
Oslo University Hospital
Author contribution: design, drafting and revision of the manuscript, and approval of the submitted version
Karsten Midtvedt, senior consultant
The author has completed the ICMJE form and declares no conflicts of interest.

GURO LØVIK GOLL

Department of Rheumatology
Diakonhjemmet Hospital
and
University of Oslo
Author contribution: design, drafting and revision of the manuscript, and approval of the submitted version
Guro Løvik Goll, senior consultant and associate professor
The author has completed the ICMJE form and declares the following conflicts of interest: she has received research funding from South-Eastern Norway Regional Health Authority, speaker fees from AbbVie (manufactures upadacitinib, adalimumab) and Novartis (secukinumab, canakinumab, ofatumumab, fingolimod and ciclosporin), as well as fees for serving on advisory boards for Janssen (golimumab, infliximab, ustekinumab). None of the aforementioned collaborations are related to vaccines, immunisation programmes or medications discussed in this article.

KRISTIN KAASEN JØRGENSEN

Department of Gastroenterology
Akershus University Hospital

and
University of Oslo
Author contribution: design, drafting and revision of the manuscript, and approval of the submitted version
Kristin Kaasen Jørgensen, senior consultant and professor
The author has completed the ICMJE form and declares the following conflicts of interest: she has received consultant fees from Ipsen and Gilead, speaker fees from Norgine and BMS, funding for participation in meetings from Advanz Pharma, Orphalan, CSL Vifor and Celltrion, as well as fees for serving on advisory boards for Astra Zeneca, Ipsen, Orphalan, dr. Falk, NovoNordisk and Celtrion.

LUDVIG A. MUNTHE

Department of Immunology
Oslo University Hospital
and
University of Oslo
Author contribution: design, drafting and revision of the manuscript, and approval of the submitted version
Ludvig A. Munthe, senior consultant and professor
The author has completed the ICMJE form and declares no conflicts of interest.

BØRRE FEVANG

Infectious Immunology Research Group
Oslo University Hospital
and
University of Oslo
Author contribution: design, drafting and revision of the manuscript, and approval of the submitted version
Børre Fevang, senior consultant and professor
The author has completed the ICMJE form and declares no conflicts of interest.

ANDERS EIVIND MYHRE

Department of Haematology
Oslo University Hospital
Author contribution: design, drafting and revision of the manuscript, and approval of the submitted version
Anders Eivind Myhre, senior consultant
The author has completed the ICMJE form and declares the following conflicts of interest: he has received research funding from South-Eastern Norway Regional Health Authority and Medac, served on advisory boards for Takeda, Bristol Myers Squibb, AstraZeneca

(manufacturer of tixagevimab/cilgavimab), Immedica Pharma, Medac and Sanofi (alemtuzumab), and has received speaker fees from Novartis, Takeda, Unimedic and Merck (cladribine). Merck, Takeda, AstraZeneca, Medac and Sanofi manufacture vaccines including for HPV and polio (Merck), influenza and polio (Sanofi), adenovirus vector-based COVID-19 vaccines (AstraZeneca) and dengue (Takeda). None of the aforementioned collaborations are related to vaccines, immunisation programmes or medications discussed in this article.

MARIUS TRØSEID

Infectious Immunology
Oslo University Hospital
and
University of Oslo
Author contribution: design, drafting and revision of the manuscript, and approval of the submitted version
Marius Trøseid, senior consultant and professor
The author has completed the ICMJE form and declares no conflicts of interest.

Chronically ill patients with a weak immune system are at increased risk of severe infections, often as a result of immunomodulatory therapy rather than the underlying disease. Many patients in this group exhibit reduced vaccine responses and require tailored vaccination regimens. Following the launch of the national Adult Immunisation Programme, all doctors must stay abreast of current guidance on vaccination in immunosuppressed patients. This clinical review article summarises interdisciplinary knowledge on patients with a reduced vaccine response.

The launch of the Adult Immunisation Programme in Norway represents a shift towards lifelong immunisation and requires general practitioners (GPs) and hospital specialists to have greater expertise in vaccinating immunosuppressed patients (1, 2). A functional adaptive immune system is needed for vaccination. The risk of infection increases with age, organ dysfunction and comorbidity, and is further amplified by immunosuppression due to reduced humoral and cellular immunity, impaired vaccine response and an increased risk of severe disease and death (3).

An increasing proportion of patients with a chronic disease or cancer, or who have undergone organ transplantation, are treated with immunomodulatory therapies that improve disease control and quality of life. However, these

medications also lead to immunosuppression, requiring additional vaccine doses or revaccination and increasing the risk of prolonged and severe infections, including influenza and pneumococcal disease (4).

This article provides a practical overview of vaccination in immunosuppressed patients, based on selected literature, national recommendations and the authors' clinical experience. Patients with primary immunodeficiency are not discussed in this article.

Factors that lead to variations in vaccine responses

Immunomodulatory therapy is used to treat a range of diseases and conditions, such as organ transplantation, multiple sclerosis, inflammatory bowel disease, malignant diseases, dermatological conditions and rheumatic disorders. These medications affect the immune system in different ways and can impair both the humoral (B-cell–mediated) and cellular (T-cell–mediated) immune responses. In the article, we discuss a selection of medications that are particularly relevant in clinical practice in Norway (Table 1) (5–26), but there are numerous other immunosuppressive medications that are not covered here.

Table 1

Immunomodulatory medications and vaccine response (5–26)

Class of medication	Examples	Effect on vaccine response	Typical increased infection risk
Corticosteroids (5, 6)	Prednisolone ≥ 20 mg/day for > 2 weeks	Reduced antibody and T-cell responses, depending on dose and duration	Opportunistic infections (Pneumocystis jirovecii, herpes viruses)
Anti-CD20 antibodies (7–10)	Rituximab, ocrelizumab, ofatumumab	Markedly reduced antibody response; with preserved T-cell function	Bacterial infections (pneumococci, meningococci), influenza, COVID-19
Plasma cell-targeted antibodies (11–13)	Daratumumab, isatuximab	Markedly reduced antibody production	Viral and bacterial infections, particularly respiratory infections
Bispecific antibodies (12, 14)	Epcoritamab, Glofitamab, Mosunetuzumab	Impaired T- and B-cell responses	Severe COVID-19, bacterial and viral infections
TNF inhibitors (15–18)	Infliximab, adalimumab	Often with preserved vaccine response	Tuberculosis, moderate bacterial infections

Class of medication	Examples	Effect on vaccine response	Typical increased infection risk
Calcineurin inhibitors (19, 20)	Tacrolimus, ciclosporin	Impaired T- and B-cell responses	Viral infections (cytomegalovirus, Epstein-Barr virus), opportunistic infections
JAK inhibitors (21)	Baricitinib, tofacitinib	Impaired T- and B-cell responses	Herpes zoster, severe viral infections
Complement inhibitors (22)	Eculizumab, ravulizumab	With preserved antibody response, but lost complement-mediated protection	Meningococcal infections
CAR-T therapy (23, 24)	Anti-CD19, anti-BCMA	Prolonged absence of antibody and T-cell responses	Severe COVID-19, bacterial and viral infections
Stem cell transplantation (25, 26)	Autologous/allogeneic	Profound and prolonged immunodeficiency	Broad risk of bacterial, viral and fungal infections

Prolonged treatment with *systemic corticosteroids* (≥ 20 mg prednisolone daily for > 2 weeks) leads to broad immunosuppression with reduced T-cell function, antibody production and inflammatory responses. This increases the risk of opportunistic infections and impairs vaccine responses, particularly during ongoing treatment. The effect is dependent on dose and duration and is gradually reduced after discontinuation (5, 6).

Antibodies against B cells and plasma cells cause profound and prolonged immunosuppression. CD20 antibodies (rituximab, ocrelizumab, ofatumumab, etc.) are used in, for example, multiple sclerosis, lymphoma, transplantation and rheumatoid arthritis, and result in effective B-cell depletion with reduced or absent vaccine responses, particularly to novel antigens, although T-cell function is largely preserved (7–10). The risk of severe bacterial (pneumococci, meningococci) and viral infections is significantly increased. Toxin-conjugated antibodies targeting B-cell markers (CD79b, CD22) also reduce antibody production. Plasma cell-targeted agents (CD38 antibodies) cause similar immunodeficiency in multiple myeloma, while CD52 antibodies (alemtuzumab) affect both T and B cells (11, 12). New bispecific antibodies and T-cell-engaging antibodies against B-cell maturation antigens (BCMA), GPRC5D, CD19 and CD20 are expected to become increasingly important and may cause combined B- and T-cell failure (13, 14).

TNF inhibitors (e.g. infliximab and adalimumab) are used for chronic inflammatory conditions such as arthritis, spondyloarthritis, inflammatory bowel disease and psoriasis. TNF blockade suppresses T-cell and macrophage activation, granuloma formation and control of intracellular pathogens, particularly *Mycobacterium tuberculosis*. Vaccine responses are generally

preserved but can be reduced when combined with other immunosuppressive agents. The risk of infection is moderately increased, particularly for severe bacterial infections and reactivation of latent tuberculosis, while the risk of severe viral infection is lower than with B-cell-targeted therapies (15–18).

Calcineurin inhibitors (tacrolimus and ciclosporin) are primarily used to prevent transplant rejection and in certain autoimmune diseases. They inhibit calcium- and calcineurin-dependent T-cell activation and reduce the cellular immune response. This impairs vaccine responses and increases the risk of viral and opportunistic infections (19, 20).

JAK inhibitors (e.g. baricitinib and tofacitinib) are used for autoimmune diseases, myeloproliferative disorders and graft-versus-host disease following allogeneic stem cell transplantation. By blocking Janus kinase signalling pathways, they suppress cytokine-driven T- and B-cell activity, reducing vaccine responses and increasing the risk of infection, particularly herpes zoster and other severe viral infections (21).

Complement inhibitors that target complement protein C5 (e.g. eculizumab and ravulizumab) are used for complement-mediated diseases such as atypical haemolytic uraemic syndrome, paroxysmal nocturnal haemoglobinuria and certain autoimmune neuromuscular disorders. Treatment causes pronounced and persistent functional hyposplenism with markedly reduced bacterial clearance and is associated with a 1000–2000-fold increased risk of invasive meningococcal disease (22). Vaccination against meningococcal disease (ACWY and B vaccines) is therefore required prior to treatment, despite the significant reduction in vaccine efficacy and the risk remaining high. Patients should also be vaccinated against *Haemophilus influenzae* type b and pneumococci. Clinical vigilance for severe infection is essential during ongoing therapy.

CAR-T cell therapy (chimeric antigen receptor T-cell therapy) involves the genetic modification of the patient's T cells to recognise tumour antigens, typically CD19 in B-cell malignancies and BCMA protein (B-cell maturation antigen) in multiple myeloma, but it is also used in certain autoimmune diseases. The treatment can lead to long-term remission but often results in persistent B-cell aplasia, reduced antibody responses and an increased risk of severe infection, including COVID-19 (23, 24).

Haematopoietic stem cell transplantation, either autologous or allogeneic, is used for haematological malignancies, bone marrow failure, immunodeficiency, metabolic disorders and certain autoimmune diseases such as multiple sclerosis, systemic sclerosis and lupus. The procedure causes profound, transient immunosuppression with markedly reduced vaccine responses and high infection risk, particularly following allogeneic transplantation (25, 26).

Risk stratification and possible measures

The composition and intensity of immunosuppression affect both the risk of infection and vaccine efficacy. With combination therapy, high cumulative doses or recent initiation of treatment, vaccine responses are often reduced,

which can require additional doses or use of adjuvanted vaccines (9, 27–31). In some situations, such as after transplantation of solid organs or blood stem cells, postponing vaccination is recommended until the risk of rejection has decreased and the daily dose of immunosuppressive medication is lower, which can take 3–6 months.

After haematopoietic stem cell transplantation, it is also important to achieve a degree of humoral and cellular immune reconstitution. Clinical experience and established guidelines indicate that some patients can achieve adequate protection with additional doses, but this must be assessed on an individual basis (32, 33). The goal is to ensure optimal vaccine protection while maintaining patient safety (Table 2) (2, 11, 18, 32, 34–36). A multidisciplinary approach involving infectious disease specialists, rheumatologists, neurologists, haematologists and other relevant specialists is important to ensure optimal timing and follow-up of vaccination.

Table 2

Vaccination strategy during use of immunomodulatory medications, based on the authors' experience and the literature (2, 11, 18, 32, 34–36)

Timing	Recommendation
Before starting therapy	Vaccinate 2–4 weeks before initiation of immunosuppressive therapy. Administer primary vaccines and boosters. Live vaccines should be considered in accordance with current guidelines from the Norwegian Institute of Public Health
During therapy	Vaccine responses should be considered reduced. Avoid live vaccines. Additional doses may be necessary.
After completion	Vaccine responses improve gradually, but the timing depends on the type of therapy. Revaccination may be necessary (particularly after anti-CD20 therapy, plasma cell-targeted therapy or stem cell transplantation)
Special situations	Organ transplantation: wait 3–6 months until maintenance dose Stem cell transplantation: restart the immunisation programme after 6–12 months

The need for vaccination must be balanced against the need for prompt initiation of treatment. Whenever possible, vaccination should be completed before starting immunosuppressive therapy, ideally at least 2–4 weeks beforehand to enable an optimal immune response. When deciding whether to vaccinate a patient prior to starting treatment, the need for immunomodulatory therapy must be weighed against the risk of infection. Live attenuated vaccines are generally contraindicated during and immediately after immunosuppressive therapy due to the risk of vaccine-associated infection (34).

Revaccination or booster doses of previous vaccines may be necessary during and after treatment with, for example, B-cell– or plasma cell-targeted antibodies, or following stem cell transplantation, due to reduced or lost vaccine efficacy (12, 32, 33, 35). Vaccination of close contacts is recommended

in selected groups to provide indirect protection to the patient, particularly against infections with a high transmission risk, such as influenza and COVID-19 (36).

Post-vaccination antibody testing (e.g. hepatitis B, COVID-19 and varicella) can be carried out to assess the need for additional doses. However, it is important to note that vaccine efficacy should not be evaluated solely on the basis of humoral responses, since cellular (T-cell) immunity may be preserved even when antibody levels are reduced (7, 37, 38).

Other vaccines of importance

In addition to the vaccines included in the Adult Immunisation Programme, there are several other vaccines that may be relevant for immunocompromised patients (2, 11, 12, 18, 32, 34–36) (Table 3). For example, booster doses of the primary vaccine against diphtheria, tetanus, pertussis and polio (DTP-IPV vaccine) are recommended every 10 years. Patients receiving immunosuppressive therapy in particular should be considered for boosters, as even moderate impairment of the immune system can increase the risk of a severe disease.

Table 3

Relevant vaccines for adults receiving immunomodulatory therapy, based on the authors' experience and the literature (2, 11, 18, 32, 34–36)

Vaccine	Standard recommendation	Relevance for immunosuppressed patients	Comment
Influenza (inactivated)	Annual	Highly important, even with reduced efficacy	Vaccinate close contacts as well
Pneumococcal	Primary vaccination (conjugate followed by polysaccharide vaccine)	Highly important	Revaccination often required
COVID-19	Seasonal	Important, but often reduced efficacy	Vaccination of close contacts can be considered
DTP-IPV vaccine	Booster every 10 years	Broadly recommended, including in moderate immunosuppression	Check primary vaccination status
MMR vaccine	2 doses for everyone born after 1960	Only before initiation of immunosuppressive therapy	Live vaccine – contraindicated during treatment
Herpes zoster (recombinant)	No general recommendation in the programme	Recommended in older and immunosuppressed patients	Non-live vaccine, safe in immunosuppression

Vaccine	Standard recommendation	Relevance for immunosuppressed patients	Comment
Hepatitis B	Risk groups (blood products, haemodialysis)	Relevant for many immunocompromised patients	Higher or additional doses often required
Meningococcal	Risk groups (asplenia, complement deficiency, eculizumab)	Important in selected patient groups	Combine ACWY and B vaccines
Varicella	Seronegative adults	Only before initiation of immunosuppressive therapy	Live vaccine – contraindicated during treatment

The measles, mumps and rubella (MMR) vaccine should be offered to adults born after 1960 who are not fully vaccinated, especially those planning pregnancy, working in health care or travelling to high-incidence areas (36). In immunosuppressed patients, live vaccines (e.g. varicella vaccine and MMR vaccine) are contraindicated, but assessing vaccination status and, where appropriate, vaccinating close contacts is important for indirect protection. Herpes zoster occurs more frequently and with greater severity in older adults and people with a weakened immune system (39). New, non-live recombinant vaccines provide an opportunity for safe and effective prevention for many in this patient group. International guidelines recommend systematic assessment of vaccination in older and immunosuppressed people (40).

Other vaccines may be relevant in selected risk groups (2). The hepatitis B vaccine is recommended for patients receiving blood products or with an increased risk of exposure (41). The meningococcal vaccine is relevant for patients with anatomical or functional hyposplenism, complement deficiencies or when using complement C5 inhibitors such as eculizumab (42). The varicella vaccine can be considered in adults without prior infection before initiation of – or after completion of – immunosuppressive therapy (43). Vaccination against human papillomavirus (HPV) should be considered following haematopoietic stem cell transplantation, particularly in women under the age of 45 (44).

Overall, we believe that the assessment of vaccination status in immunosuppressed patients should be broad and systematic and not limited to the vaccines included in the Adult Immunisation Programme (Table 4) (2, 11, 18, 32, 34–36). A systematic approach to additional vaccines can prevent severe infections, reduce complications and improve patient safety for this vulnerable group.

Table 4

Risk stratification in adults undergoing planned or ongoing immunomodulatory therapy, based on the authors' experience and the literature (2, 11, 18, 32, 34–36)

Risk level	Examples	Vaccination strategy	Additional measures
Low	Low-dose steroids (< 10 mg prednisolone/day)	Follow the Adult Immunisation Programme	Check vaccination status
Moderate	TNF inhibitor, combination therapy (e.g. TNF inhibitor + methotrexate), calcineurin inhibitor	Additional doses as needed; avoid live vaccines	Close monitoring; consider prophylaxis
High	Anti-CD20, BiTE, CAR-T, stem cell/organ transplantation	Planned vaccination prior to initiation; revaccination afterwards. Avoid live vaccines.	Antibody measurement; prophylaxis (antiviral/antibacterial)

Division of responsibilities and coordination

Following the launch of the Adult Immunisation Programme, vaccination is now an established part of the health service's core remit and requires structured coordination between primary care and the specialist health service. Primary care has overall responsibility for the administration of vaccines, while the specialist health service, in selected cases, performs risk assessments and provides treatment-related vaccine advice for patients at increased risk of infection. Coordination between primary care and the specialist health service is crucial for ensuring appropriate prioritisation and vaccination practices.

The article has been peer-reviewed.

REFERENCES

1. Folkehelseinstituttet. Voksenvaksinasjonsprogrammet – håndbok for helsepersonell 2025. https://www.fhi.no/va/vaksinasjonshandboka/vaksinasjon/voksenvaksinasjonsprogrammet/ Accessed 9.1.2026.

2. Folkehelseinstituttet. Vaksinasjon ved immunsvikt 2025. https://www.fhi.no/va/vaksinasjonshandboka/vaksinasjon-ved-sykdom/vaksinasjon-ved-medfodt-immunsvikt/ Accessed 19.9.2025.

3. Liu Z, Liang Q, Ren Y et al. Immunosenescence: molecular mechanisms and diseases. Signal Transduct Target Ther 2023; 8: 200. [PubMed] [CrossRef]

4. Memoli MJ, Athota R, Reed S et al. The natural history of influenza infection in the severely immunocompromised vs nonimmunocompromised hosts. Clin Infect Dis 2014; 58: 214–24. [PubMed][CrossRef]

5. Galmiche S, Luong Nguyen LB, Tartour E et al. Immunological and clinical efficacy of COVID-19 vaccines in immunocompromised populations: a

systematic review. Clin Microbiol Infect 2022; 28: 163–77. [PubMed] [CrossRef]

6. Chastain DB, Spradlin M, Ahmad H et al. Executive Summary: State-of-the-Art Review: Unintended Consequences: Risk of Opportunistic Infections Associated with Long-term Glucocorticoid Therapies in Adults. Clin Infect Dis 2024; 78: 811–2. [PubMed][CrossRef]

7. Wolf AS, Ravussin A, König M et al. T cell responses to SARS-CoV-2 vaccination differ by disease-modifying therapy for multiple sclerosis. JCI Insight 2023; 8. doi: 10.1172/jci.insight.165111. [PubMed][CrossRef]

8. Riise J, Meyer S, Blaas I et al. Rituximab-treated patients with lymphoma develop strong CD8 T-cell responses following COVID-19 vaccination. Br J Haematol 2022; 197: 697–708. [PubMed][CrossRef]

9. König M, Lorentzen AR, Torgauten HM et al. Humoral immunity to SARS-CoV-2 mRNA vaccination in multiple sclerosis: the relevance of time since last rituximab infusion and first experience from sporadic revaccinations. J Neurol Neurosurg Psychiatry 2023; 94: 19–22. [PubMed][CrossRef]

10. Oksbjerg NR, Nielsen SD, Blinkenberg M et al. Anti-CD20 antibody therapy and risk of infection in patients with demyelinating diseases. Mult Scler Relat Disord 2021; 52. doi: 10.1016/j.msard.2021.102988. [PubMed] [CrossRef]

11. Rajkumar SV. Multiple myeloma: 2024 update on diagnosis, risk-stratification, and management. Am J Hematol 2024; 99: 1802–24. [PubMed][CrossRef]

12. Krajnc N, Bsteh G, Berger T et al. Monoclonal Antibodies in the Treatment of Relapsing Multiple Sclerosis: an Overview with Emphasis on Pregnancy, Vaccination, and Risk Management. Neurotherapeutics 2022; 19: 753–73. [PubMed][CrossRef]

13. Ravi G, Costa LJ. Bispecific T-cell engagers for treatment of multiple myeloma. Am J Hematol 2023; 98 (Suppl 2): S13–21. [PubMed][CrossRef]

14. Reynolds G, Cliff ERS, Mohyuddin GR et al. Infections following bispecific antibodies in myeloma: a systematic review and meta-analysis. Blood Adv 2023; 7: 5898–903. [PubMed][CrossRef]

15. Alirezaylavasani A, Egner IM, Dahl B et al. Deficient SARS-CoV-2 hybrid immunity during inflammatory bowel disease. Clin Immunol 2025; 271. doi: 10.1016/j.clim.2024.110404. [PubMed][CrossRef]

16. Wolf AS, Bjørlykke KH, Ørbo HS et al. T cell responses to repeated SARS-CoV-2 vaccination and breakthrough infections in patients on TNF inhibitor treatment: a prospective cohort study. EBioMedicine 2024; 108. doi: 10.1016/j.ebiom.2024.105317. [PubMed][CrossRef]

17. Jørgensen KK, Høivik ML, Chopra A et al. Humoral immune response to SARS-CoV-2 vaccination in patients with inflammatory bowel disease on immunosuppressive medication: association to serum drug levels and disease type. Scand J Gastroenterol 2023; 58: 874–82. [PubMed][CrossRef]

18. van Assen S, Agmon-Levin N, Elkayam O et al. EULAR recommendations for vaccination in adult patients with autoimmune inflammatory rheumatic diseases. Ann Rheum Dis 2011; 70: 414–22. [PubMed][CrossRef]

19. Kared H, Alirezaylavasani A, Lund KP et al. Hybrid and SARS-CoV-2-vaccine immunity in kidney transplant recipients. EBioMedicine 2023; 97. doi: 10.1016/j.ebiom.2023.104833. [PubMed][CrossRef]

20. Hovd M, Åsberg A, Munthe LA et al. Humoral vaccine response and breakthrough infections in kidney transplant recipients during the COVID-19 pandemic: a nationwide cohort study. EClinicalMedicine 2023; 60. doi: 10.1016/j.eclinm.2023.102035. [PubMed][CrossRef]

21. Sunzini F, McInnes I, Siebert S. JAK inhibitors and infections risk: focus on herpes zoster. Ther Adv Musculoskelet Dis 2020; 12: 1759720X20936059.

22. McNamara LA, Topaz N, Wang X et al. High Risk for Invasive Meningococcal Disease Among Patients Receiving Eculizumab (Soliris) Despite Receipt of Meningococcal Vaccine. MMWR Morb Mortal Wkly Rep 2017; 66: 734–7. [PubMed][CrossRef]

23. Abid MA, Abid MB. SARS-CoV-2 vaccine response in CAR T-cell therapy recipients: A systematic review and preliminary observations. Hematol Oncol 2022; 40: 287–91. [PubMed][CrossRef]

24. Bishop MR. Late complications and long-term care of adult CAR T-cell patients. Hematology (Am Soc Hematol Educ Program) 2024; 2024: 109–15. [PubMed][CrossRef]

25. Federico L, Tvedt THA, Gainullin M et al. Robust spike-specific CD4+ and CD8+ T cell responses in SARS-CoV-2 vaccinated hematopoietic cell transplantation recipients: a prospective, cohort study. Front Immunol 2023; 14. doi: 10.3389/fimmu.2023.1210899. [PubMed][CrossRef]

26. European Conference on Infections in Leukaemia group. Vaccination of haemopoietic stem cell transplant recipients: guidelines of the 2017 European Conference on Infections in Leukaemia (ECIL 7). Lancet Infect Dis 2019; 19: e200–12. [PubMed][CrossRef]

27. Syversen SW, Jyssum I, Tveter AT et al. Immunogenicity and Safety of Standard and Third-Dose SARS-CoV-2 Vaccination in Patients Receiving Immunosuppressive Therapy. Arthritis Rheumatol 2022; 74: 1321–32. [PubMed][CrossRef]

28. König M, Torgauten HM, Tran TT et al. Immunogenicity and Safety of a Third SARS-CoV-2 Vaccine Dose in Patients With Multiple Sclerosis and

Weak Immune Response After COVID-19 Vaccination. JAMA Neurol 2022; 79: 307–9. [PubMed][CrossRef]

29. Midtvedt K, Vaage JT, Heldal K et al. Fourth dose of the SARS-CoV-2 vaccine in kidney transplant recipients with previously impaired humoral antibody response. Am J Transplant 2022; 22: 2704–6. [PubMed][CrossRef]

30. Jyssum I, Kared H, Tran TT et al. Humoral and cellular immune responses to two and three doses of SARS-CoV-2 vaccines in rituximab-treated patients with rheumatoid arthritis: a prospective, cohort study. Lancet Rheumatol 2022; 4: e177–87. [PubMed][CrossRef]

31. Åsberg A, Hovd M, Kjellevold SA et al. Humoral Response After 6 or More Successive Doses of SARS-CoV-2 mRNA Vaccines in Kidney Transplant Recipients-Should We Keep Vaccinating? Transplantation 2023; 107: e279–80. [PubMed][CrossRef]

32. de la Cámara R, Meisel R, Vaccinations I et al. red. The EBMT Handbook: Hematopoietic Cell Transplantation and Cellular Therapies. Cham: Springer, 2024.

33. Buchan CA, Agbayani G, Hueniken K et al. Immunogenicity and Safety of Third, Fourth, and Subsequent COVID-19 Vaccine Doses in Recipients of Hematopoietic Cell Transplantation and Cellular Therapy. Transplant Cell Ther 2025; S2666-6367(25)01551-9.

34. Alnaimat F, Sweis JJG, Jansz J et al. Vaccination in the Era of Immunosuppression. Vaccines (Basel) 2023; 11: 1446. [PubMed][CrossRef]

35. Otero-Romero S, Lebrun-Frénay C, Reyes S et al. ECTRIMS/EAN consensus on vaccination in people with multiple sclerosis: Improving immunization strategies in the era of highly active immunotherapeutic drugs. Mult Scler 2023; 29: 904–25. [PubMed][CrossRef]

36. Folkehelseinstituttet. Vaksinasjonshåndboka. https://www.fhi.no/va/vaksinasjonshandboka/ Accessed 20.2.2026.

37. Tran TT, Vaage EB, Mehta A et al. Titers of antibodies the receptor-binding domain (RBD) of ancestral SARS-CoV-2 are predictive for levels of neutralizing antibodies to multiple variants. bioRxiv. Preprint 13.4.2022. https://www.biorxiv.org/content/10.1101/2022.03.26.484261v2 Accessed 20.2.2026.

38. Christensen IE, Jyssum I, Tveter AT et al. The persistence of anti-Spike antibodies following two SARS-CoV-2 vaccine doses in patients on immunosuppressive therapy compared to healthy controls-a prospective cohort study. BMC Med 2022; 20: 378. [PubMed][CrossRef]

39. Curran D, Doherty TM, Lecrenier N et al. Healthy ageing: Herpes zoster infection and the role of zoster vaccination. NPJ Vaccines 2023; 8: 184. [PubMed][CrossRef]

40. Vielot NA, Jonsson Funk M, Stürmer T et al. Effectiveness of Recombinant Herpes Zoster Vaccine in the U.S. Medicare Population, 2018 to 2019, by Immunocompetence and Prior Receipt of Live Zoster Vaccine. Ann Intern Med 2025; 178: 1728–36. [PubMed][CrossRef]

41. Folkehelseinstituttet. Hepatitt B-vaksine og hepatitt B-immunglobulin – håndbok for helsepersonell. https://www.fhi.no/va/vaksinasjonshandboka/vaksiner-mot-de-enkelte-sykdommene/hepatitt-b-vaksinasjon-og-immunglobulin/#indikasjoner-og-mlgrupper Accessed 3.2.2026.

42. Folkehelseinstituttet. Meningokokkvaksine – håndbok for helsepersonell. https://www.fhi.no/va/vaksinasjonshandboka/vaksiner-mot-de-enkelte-sykdommene/meningokokkvaksinasjon/ Accessed 3.2.2026.

43. Folkehelseinstituttet. Varicellavaksine (vannkopper) og varicella-zoster immunglobulin – håndbok for helsepersonell.https://www.fhi.no/va/vaksinasjonshandboka/vaksiner-mot-de-enkelte-sykdommene/aricellavaksine-og-varicella-zoster-immunglobulin/#indikasjoner-og-mlgrupper Accessed 3.2.2026.

44. Folkehelseinstituttet. HPV-vaksine (Humant papillomavirus) – håndbok for helsepersonell. https://www.fhi.no/va/vaksinasjonshandboka/vaksiner-mot-de-enkelte-sykdommene/hpv-vaksinasjon/#indikasjoner-og-mlgrupper Accessed 3.2.2026.

Publisert: 13 April 2026. Tidsskr Nor Legeforen. DOI: 10.4045/tidsskr.25.0555
Received 18.9.2025, first revision submitted 13.1.2026, accepted 20.2.2026.