Overview of infections as an etiologic factor and complication in patients with vasculitides

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Abstract
Vasculitides, a form of inflammatory autoimmune disease targeting the vessels, constitute an entity with significant morbidity and mortality. Infections have long been associated with vasculitides as a result of the incident immunosuppression following treatment induction and maintenance. Several microbial pathogens have been described as etiologic factors of infections in this patient population according to the type of vessels affected. Intense research has also been recently conducted in the interplay between vasculitides and certain viral infections, namely human immunodeficiency virus and severe acute respiratory syndrome coronavirus 2. Of note, a plethora of scientific evidence is available regarding the role of infections as triggering factors for vasculitides. Among the main mechanisms implicated in this direction are the activation of B and T cells, the direct endothelial insult, the immune complex-mediated vascular injury, and the cell-mediated, type IV hypersensitivity vessel damage. Therefore, this review aims to summarize all the available evidence concerning this bidirectional interplay between infections and vasculitides.

Keywords Vasculitis · Infection · COVID-19 · HIV

Introduction
Vasculitides are a heterogeneous group of autoimmune diseases with great morbidity and mortality, characterized by fibrinoid necrosis and the presence of inflammatory leukocytes, leading to damage of the vessel wall [1]. Inflammation in this patient population leads to narrowing or even obstruction of the vessels resulting in reduced blood perfusion and the development of ischemic damage to the tissues and organs.

Both the size of the vessels and the organs affected are different between the different types of vasculitis and, therefore, their clinical manifestations vary [1]. Vasculitides may be pronominally classified into large-, medium-, and small-sized vessel vasculitides, as well as into primary or secondary vasculitides, including infectious or paraneoplastic vasculitides. In this review article, we first provide the latest evidence regarding the association between infections and vasculitides in an effort to increase awareness of the infectious etiology of vasculitis.

Search strategy
We performed a literature search in PubMed, Google Scholar, and Web of Science from inception till 15th January 2022, using the following keywords: vasculitis, infection, bacterial infection, viral infection, coronavirus disease-19, COVID-19, SARS-CoV-2, human immunodeficiency virus, HIV. Additionally, articles were extracted from the reference list of the retrieved articles if they were deemed relevant. Specifically, we focused our attention on papers published within the last 5 years.
Evidence for the relationship between infections and vasculitis

In the past, historical diseases such as tuberculosis or syphilitic aortitis have long been suspected to be triggering factors for many types of vasculitis [2].

Many different types of vasculitides may be associated with infections (Table 1). On the other hand, patients with vasculitis may develop infections, which sometimes mimic a relapse of the disease.

When an infection has been diagnosed in a patient with vasculitis, the subsequent question is to determine whether vasculitis is related or not to the infection and how to treat both conditions in the most appropriate and safest ways [10, 22, 23]. So far, a causal relationship between infection and vasculitis has only been established in a few instances, and the pathophysiologic mechanisms remain hypothetical [2].

Type of vasculitis and different infectious agents involved

In the small-vessel vasculitis, including ANCA-associated vasculitides (AAV) [24, 25] and/or small-vessel, immune complex-mediated vasculitis [4, 5, 11], the possible role of infection in triggering de novo disease and relapse has been extensively investigated and a clear association has been demonstrated. On the other hand, there is only indirect evidence to support an infectious etiology for Kawasaki’s disease, even though numerous organisms have been proposed but not proven [26].

In patients with granulomatosis with polyangiitis (GPA), S. aureus was the most commonly isolated organism in cultures from the upper airways that have been associated with an increased risk of relapse [24]. In light of this evidence, a cyclical pattern of GPA occurrence in cases of an infectious etiology is supported and is exhibited periodically with a maximum peak every 7.7 years [25].

Moreover, microscopic polyangiitis (MPA) is also associated with infections and environmental factors. It is suggested that infection is a major causal factor in the formation of ANCA. Importantly, substantial differentiation of glomerulonephritis due to infection and immune complex deposition versus ANCA-associated vasculitis could be easily performed with a kidney biopsy [6]. Indeed, different case reports have been described, whereby infective endocarditis caused by E. faecalis, Streptococcus, and Bartonella species were also related to ANCA vasculitis and markedly elevated levels of PR3-ANCA [6].

On the contrary, in the setting of eosinophilic granulomatosis with polyangiitis (EGPA), the majority of cases are idiopathic, associated with inhaled antigens rather than infections. Herein, vaccination and desensitization have been reported as triggering factors [27]. However, in EGPA the epidemiological data may be confounded by the severity of preceding asthma [28].

In IgA vasculitis-Henoch-Schönlein purpura (HSP), it is suggested that infections can trigger immune complex

| Study Mechanisms | Type of infection | Type of vasculitis |
|------------------|-------------------|--------------------|
| **Bacteria**     | Direct invasion   | Mycobacterium TBC  |
| [3–9]            | or Immune complex-mediated | Non-TBC mycobacterial GPA |
|                  | S. aureus         | Streptococcus HSP |
|                  | Gram-negative     | Leukocytoclastic vasculitis |
|                  | Rickettsia        | Cutaneous vasculitis |
|                  | *Pseudomonas aeruginosa* |                      |
| **Virus**        | Direct endothelial invasion | HBV PAN |
| [10–16]          | or Indirect autoimmune mechanisms ↓
|                  | by immunological factors or
|                  | by direct vascular injury |
|                  | HIV Cryoglobulinemic Vasculitis |
|                  | HTLV-1 Giant cell arteritis |
|                  | Erythrovirus B19 HSP |
|                  | CMV |
|                  | VZV Mycotic aneurism |
| **Fungi**        | Direct invasion   | Toxoplasmosis |
| [17]             | or Septic embolism | Trichinosis |
|                  |                  | Toxocariosis |
| **Parasites**    | Direct invasion   | Cutaneous |
| [18–21]          |                  | Vasculitis |

TBC tuberculosis, GPA granulomatosis with polyangiitis, HSP Henoch-Schönlein purpura, HBV hepatitis B virus, HCV hepatitis C virus, HIV human immunodeficiency virus, HTLV-1 human T-cell lymphotropic virus type 1, PAN polyarteritis nodosa, CMV cytomegalovirus, VZV varicella-zoster virus
deposition. Although long-term observations are lacking, an interesting concept was presented as patients exhibited a constantly increased risk for serious infections during follow-up. Additionally, a higher rate of upper respiratory tract infections has been shown [3]. Concerning children with IgA vasculitis, specific inflammatory factors may be attributed and have a lasting effect on immune competence [4]. Another point of importance is that the incidence of IgA vasculitis exhibited seasonal increases in the spring and decreases in the winter, which may be related to a higher frequency of upper respiratory tract infections during the coldest months of the year. Interestingly, in the majority of patients with HSP there is an infection of the upper respiratory tract, indicative of a potential microbial etiology of the disease. Among children aged less than 10 years, 99.5% of cases suffer from either IgA vasculitis or Kawasaki disease, both exhibiting a seasonal pattern paralleling infections [29]. IgA vasculitis has also been associated with influenza infection [11].

Last but not least, leukocytoclastic vasculitis may also be a manifestation of bacterial infection [5]. Etiologically, the appearance of small-vessel cutaneous vasculitis is associated with drug reactions or certain viral or bacterial infections. Among patients with cutaneous vasculitis, beta-lactams, analgesics, or non-steroidal anti-inflammatory agents are common drugs associated with the disease, which usually have a good clinical outcome [30]. In leukocytoclastic vasculitis, the presence of upper respiratory tract infections shortly before the development of vasculitis was more common than in those with IgA vasculitis [5]. Cutaneous vasculitis has been described in patients with cystic fibrosis due to respiratory infections due to *Pseudomonas aeruginosa*, *S. aureus*, *Haemophilus influenza*, and *Burkholderia cepacia* complex [8, 31, 32]. Furthermore, a cutaneous small-vessel vasculitis may occur in childhood after an infection caused by the atypical bacterial pathogen *Mycoplasma pneumoniae* [33].

**Hepatitis B virus-associated polyarteritis nodosa**

Polyarteritis nodosa (PAN), a medium-vessel vasculitis, frequently results from hepatitis B virus infection (HBV-PAN). HBV-PAN has become the most convincingly documented, immunologically-mediated, infection-associated systemic vasculitis and the single most important feature in confirming the diagnosis of PAN [13]. One of the highest rates reported comes from an area endemic for HBV infection and accounts for 30% to be HBV positive [34]. Control of the viral infection is mainly based on the use of antiviral drugs with the current availability of potent agents. Other rare cases of PAN have been associated with nontuberculous mycobacterial infection [14], with cutaneous polyarteritis nodosa occurrence in the setting of *Mycobacterium tuberculosis* infection also being described [35].

**Hepatitis C virus-associated cryoglobulinemic vasculitis**

Cryoglobulinemic vasculitis is the most frequent extrahepatic manifestation in patients infected with the hepatitis C virus (HCV) [10]. This causative relationship between hepatitis C and cryoglobulinemic vasculitis is well-established in more than 80% of the patients [12]. Its incidence has decreased over the past few decades, with direct-acting antivirals not always effective at eradicating or preventing the relapse of this complication despite achieving a sustained viral response [36–38].

**Human immunodeficiency Virus-associated vasculitides**

Human immunodeficiency virus (HIV) positive patients may also develop vasculitis, either mediated by immunological factors or by direct vascular injury, as well as by the restoration of protective pathogen-specific cellular immune response owing to the immune restoration inflammatory syndrome induced by antiretroviral treatment [39]. Hypersensitivity reactions should be considered as a possible etiology of vasculitis in HIV-infected patients [40]. HIV-associated PAN-like disease and Kawasaki-like syndrome have also been described, with significant differences when compared to the classic manifestations of PAN and Kawasaki disease, respectively [39]. Regarding large vessel vasculitis, it is more commonly encountered in HIV patients at an advanced disease stage, with multiple aneurysms and occlusions in less typical locations, sharing histologic similarities with Takayasu arteritis [41]. It should be noted that this large vessel vasculitis occurs independently of CD4 count and viral load, as well as in patients after starting antiviral therapy indicating the immune reconstitution inflammatory syndrome (IRIS) [42]. Physicians should be aware that vasculitis may have a heterogeneous presentation and can occur in association with HIV infection [15].

**Coronavirus disease-19-associated vasculitides**

The role of the recent severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), characterized by an inflammatory cytokine storm and incident endotheliitis [43, 44], in the pathogenesis of IgA-mediated vasculitis needs to be determined. Recently the occurrence of Henoch-Schonlein purpura secondary to a SARS-CoV-2 infection in children and adults was mentioned in several case reports [45]. Since SARS-CoV-2 causes a mucosal infection, the incident IL-6 production might be responsible for the
stimulation of poor glycosylation/galactosylation of IgA1, leading to the formation of galactose-deficient IgA1, thus contributing to IgA vasculitis development and progression [46]. Case reports of AAV following coronavirus disease-19 (COVID-19) have also been described, presenting with renal involvement and contrasting prognosis [47]. Moreover, COVID-19 has been linked with the manifestation of other forms of vasculitis, such as Kawasaki disease and leukocytoclastic vasculitis [48–50]. SARS-CoV-2 may also lead to a small vessel vasculitis not involving the main coronaries [51]. Evidence of central nervous system vasculitis following COVID-19 was confirmed via biopsy despite a mild form of SARS-CoV-2 infection [52]. Garcia-Ramos et al. reviewed the available evidence on the incidence of autoimmune diseases in COVID-19 patients [53]. In incidence vasculitis patients, they noted a male sex predisposition, with the majority of patients exhibiting a mild-to-moderate COVID-19 disease course [53]. Vasculitis onset was reported approximately one month after SARS-CoV-2 infection and completely resolved in the vast majority of cases [53]. In a recently reported positron emission tomography/computed tomography study of recovered adult COVID-19 patients with residual symptoms, a higher target-to-blood pool ratio was observed in the thoracic aorta, right iliac artery, and femoral artery of COVID-19 patients compared to control, indicating a persistent vascular inflammation which could be responsible for vasculitic manifestations in the long-term recovery period [54]. AAV may as well be a complication of the Long-COVID-19 syndrome, with deleterious outcomes [55].

In children, Multisystem Inflammatory Syndrome (MIS-C) is a newly defined post-viral myocarditis inflammatory vasculopathy following COVID-19 infection [56], which can be complicated with giant coronary aneurysm formation [57]. Importantly, this syndrome differs in several aspects (epidemiology, clinical, and immunological findings) from Kawasaki disease [58]. This syndrome can also be found in adult patients (MIS-A), usually four months after the acute phase of COVID-19, presenting with multiorgan dysfunction frequently requiring intensive care unit admission, while a minority of patients may present with Kawasaki disease [59]. It should be stressed, however, that prompt immunomodulatory treatment may lead to the regression of myocardial injury and the reversibility of left ventricular dysfunction [60].

Further research in this field is required, however, to better define the pathophysiologic basis of autoimmune diseases incidence in COVID-19 [61]. It should also be stated that vaccination against SARS-CoV-2 may also be complicated with cutaneous vasculitic phenomena or even IgA vasculitis and AAV [62–66].

Other virus-associated vasculitides

Human T-cell lymphotropic virus type 1 (HTLV-1) has been shown to infect human endothelial cells and may explain the CNS vasculitis associated with the progressive spastic paraplegia seen with HTLV-1 infections [67]. Other viruses such as Erythrovirus B19, cytomegalovirus, and varicellazoster virus have also been reported to be associated with or implicated in the development of vasculitides [10]. Additionally, norovirus infection can precipitate the worsening of an underlying HSP vasculitis and lead to acute clinical decompensation [68].

Fungal and parasitic disease-associated vasculitides

Fungi diseases can also cause vasculitides. Herein, the proposed mechanism involves the direct invasion of blood vessels or septic embolization, leading to the well-known feature of ‘mycotic aneurysm’ [17]. It is noteworthy that various induction therapies in AAV also result in opportunistic fungal infections [69].

A plethora of parasitic diseases has been associated with vasculitis. Toxoplasmosis, trichinosis, strongyloidiasis, ascariasis, sarcocystosis, amoebiasis, leishmaniasis, and toxocariasis have been anecdotally reported in conjunction with vasculitis with cutaneous and/or systemic manifestations [18–21, 70].

Mechanisms of infection-associated vasculitis

Studies have provided valuable information on the mechanism of inflammation and innate immunity (Fig. 1). The mechanisms of infection-related vasculitis involve direct and indirect pathogen invasion. Direct pathogen invasion is detected within the blood vessel walls and is characterized by smooth muscle cell (SMC) accumulation, endothelial dysfunction, expression of reactive oxygen species (ROS), cytokines, chemokines, cellular adhesion molecules, and damage of the vessel wall [71]. It is also suggested that the pathogenesis of vasculitis differs according to the pathogenic organisms. The indirect mechanisms of infection-related vasculitis involve immune-mediated injury to the vessel walls, such as immune-complexes molecular mimicry, ANCA, cytokines, superantigens, autoantigen complementarity, and T cell immune response [71].

Activation of T and B cells

Infections stimulate autoimmune responses with shared epitopes between pathogens and host, upregulated heat shock proteins, and stimulated lymphocytes [22]. Circulating
Toxins often act as superantigens which are exotoxins produced by a small group of bacteria, primarily *S. aureus* and *Streptococcus pyogenes* [72]. These induce oligoclonal activation of T cells through an antigen-independent mechanism [73].

Superantigens also stimulate B cells to produce autoantibodies that may be involved in the pathogenesis of vasculitis (Fig. 2, Panel a) [22, 23]. The ‘classic neutrophil pathway’ has been described as a cause of necrotizing vasculitis and has been studied and confirmed by several groups. An additional ‘T-cell pathway’ has also been proposed, mainly causing granulomatous inflammation, promoting necrotizing vasculitis [74]. Infections are the starting point of both pathways and trigger the priming of neutrophils [74].

**Immune complex-mediated damage**

Immune complex-mediated damage represents a reaction of type III hypersensitivity where the antigens are the infectious agents or antigenic portions of them after the zone of equivalence is reached. The immune complexes precipitate and become trapped within vessel walls, stimulating an immune response (Fig. 2, Panel b) [75]. Type III hypersensitivity produces soluble immune complexes and, under certain conditions, may occasionally produce devastating tissue damage. A disease caused by soluble immune complexes may also be due to autoimmunity when the antigen involved is self-derived. Studies of circulating complement levels have shown a correlation with disease activity [75].

Defective handling of antigenic peptides, whether due to high antigenic load or abnormally functioning immune regulatory mechanisms, in chronic viral infections such as hepatitis C or hepatitis B, might contribute to a state of persistent antigenemia, stimulation of an immune response with subsequent release of antigen-directed antibodies, and the formation of immune complexes. Subsequent complement activation generates the chemotactic factor C5α, which promotes the accumulation of circulating neutrophil and monocytes-macrophages [76]. It has been proposed that factors released by ANCA-activated neutrophils activate the alternative pathway of complement, resulting in enhanced recruitment and activation of neutrophils [77]. The alternative pathway is activated by a variety of cellular surfaces, including those of certain bacteria, viruses, fungi, and parasites. Sequential non-enzymatic protein–protein interactions among the terminal complement proteins initiated by C5a lead to the formation of the membrane attack complex (MAC). Because biological activities of C5α and MAC play a role in the pathogenesis of endothelial injury, this alternative pathway is now considered pathogenically important, and complement inhibitors (such as anti-C5α) may have efficacy in AAV, with C5α potentially being an important therapeutic target [78]. Immunosuppressive therapy with glucocorticoids underpins current treatment for AAV. Agents targeting the complement system such as eculizumab, a monoclonal antibody that prevents the formation of C5a and C5b-9, and avacopan, a small molecule inhibitor of C5aR, may represent an alternative to steroids [9, 79].

Neutrophils are required for the development of bacteria-associated vasculitides. They can sometimes be attributed to an antigen excess which in turn causes a rise in circulating immune complexes and inflammatory mediator deposition.
within the vessel walls, with subsequent complement activation and blood vessel wall damage [75].

**Direct invasion of the endothelial cells**

Vasculitides following bacterial infections may occur from direct invasion of the endothelial cells as a result of an extension of a localized focus of infection affecting blood vessels or due to blood-borne septic embolization (Fig. 2, Panel c) [80].

Direct necrotizing vessel wall destruction can be induced by *Pseudomonas aeruginosa* or *Legionella pneumophila* in the lungs or *Fusobacterium necrophorum* in the internal jugular veins after pharyngitis [80]. In addition, fungi, protozoa, and helminths usually cause vasculitis through direct invasion of the vessel walls. Several bacteria, including *Pseudomonas aeruginosa*, *S. aureus*, *Burkholderia cepacia*, *L. monocytogenes*, and *Haemophilus influenzae*, have been incriminated [6]. Direct endothelial cell invasion can also be the main pathogenic process in infections caused by CMV and herpes simplex virus [80]. A study reported that intracerebral varicella-zoster virus (VZV) antigens and DNA could be isolated from the walls of temporal arteries of a large proportion of patients affected with giant cell arteritis or aortitis [16].

**Cell-mediated hypersensitivity type IV**

Antigenic exposure may attract lymphocytes which liberate cytokines causing tissue damage and further activation of macrophages and lymphocytes (Fig. 2, Panel d) [81]. The abnormal expression of adhesion molecules and cytokines in vascular endothelium in most vasculitis syndromes as a manifestation of endothelial dysfunction can be triggered by a variety of stimuli, including infectious agents, immune complexes, and anti-endothelial cell antibodies [2].

**Infections in immunosuppressed patients with vasculitis**

The interest in infection-related vasculitides has been boosted over the last 2 decades by the development of new molecular techniques and the proof of true associations between viral infections and systemic vasculitis [82]. The aggressive treatment of vasculitis incurs a variety of adverse effects, among which infection is the most common and
prednisolone led to a higher odd of COVID-19 severity and vasculitic disease activity and the intake of 10 mg/day of an adverse COVID-19 prognosis, while at least moderate seen in older male subjects [87]. Moreover, the presence of comorbid respiratory disease might represent an additional risk factor, as shown by Rutherford et al. in a multicenter cohort of 65 patients with systemic vasculitis and COVID-19 [88].

Immunosuppressive agents and infections in vasculitides

The rate of severe infections and infection-related mortality in patients with severe vasculitis treated with immunosuppressive agent induction therapy was high. A recent meta-analysis including four studies and a total of 888 subjects estimated that in randomized controlled trials of necrotizing vasculitis, GPA, MPA, EGPA, and PAN treated with CYC combined with high dose glucocorticoids (GC) (mean cumulative doses of CYC were 2.7–50.4 g and of GC were 6–13 g), the risk of severe infection was 2.2%, the risk of any infection was at 5.6%, and an infection-related death was estimated at 1.7% per year per gram of CYC [23]. Interestingly, age, serum creatinine, and cumulative GC dose were not significantly associated with the rate of severe infections [23]. It is also suggested that oral CYC, which had a higher cumulative CYC dose compared to intravenous CYC, showed lower infection rates [89].

As far as rituximab therapy is concerned, a considerable percentage of patients with AAV may be susceptible to severe infections, with increasing age, impaired renal function, and lower body mass index acting as risk factors [90, 91]. Dosing regimens (four-dose and two-dose) do not differ in the rate of incident infections [92]. In a recently reported Bayesian network meta-analysis of randomized controlled trials, mycophenolate mofetil was likely the safest treatment option with regard to severe infections in patients with AAV, followed by CYC, azathioprine, rituximab, and methotrexate [93]. The differences, however, were marginal and the only statistically significant comparison involved mycophenolate mofetil and methotrexate [93]. A combination of immunosuppressants (rituximab, CYC, GC) was not associated with a higher rate of severe infections in a cohort of patients with life-threatening AAV [94]. However, high-dose GC added to rituximab may be related to a greater incidence of severe infections in a randomized clinical trial of patients with AAV but without severe glomerulonephritis or alveolar hemorrhage [95]. At the same time, the low-dose GC regimen was non-inferior regarding disease remission induction at six months [95].

COVID-19 in patients with vasculitides

The impact of SARS-CoV-2 infection and COVID-19 in patients with preexisting vasculitis also deserves an honorable mention. The presence of vasculitis was associated with 1.6-fold higher odds of hospitalization, while the use
of disease-modifying anti-rheumatic drugs did not affect the need for hospitalization [96]. In the retrospective cohort study by Sattui et al., approximately 50% of patients required hospitalization and 15% died [97]. Among the identified risk factors were the increased age, male sex, comorbidity burden, and high-dose glucocorticoids [97]. Similar risk factors were proposed by the results of the COVID-19 Global Rheumatology Alliance physician-reported registry of patients with rheumatic diseases and confirmed or suspected SARS-CoV-2 infection, where the use of rituximab, sulfasalazine, and other immunsuppressants (azathioprine, cyclophosphamide, ciclosporin, mycophenolate, or tacrolimus) was additionally linked to increased death rates compared to methotrexate monotherapy [98]. Interestingly, the use of anti-tumor necrosis factor (TNF) agents was associated with a decreased odds of hospitalization [96]. Additionally, the use of the monoclonal antibody bamlanivimab was proven efficacious in a small cohort of patients with COVID-19 and AAV on rituximab therapy [99], a subgroup characterized by an impaired immune response to SARS-CoV-2 vaccination [100]. However, a booster dose may be met with greater success in these patients and is, therefore, warranted [101]. It is also worthwhile mentioning that vaccination against SARS-CoV-2 is well-tolerated and generally safe in patients with inflammatory rheumatic diseases, including vasculitides, with low rates of breakthrough infections [102]. However, disease relapses have been reported in patients with AAV and HSP [103, 104]. Finally, the impact of the pandemic in patients with vasculitides may be indirect through the interruption of immunsuppressive treatment, subsequently leading to increased rates of disease flares [105].

Conclusions

The relationship between infection and vasculitis is complex. Infections have long been suspected to be triggering factors for many types of vasculitides. A causal relationship has only been firmly established in a few instances using an epidemiological approach. Of great importance is the recognition of the infectious origin of vasculitides. Treatment strategies differ from those applied to non-infectious vasculitides. A high index of suspicion is required because clinical features are not always specific. Thus, an infection should always be excluded based on appropriate examinations, and, if confirmed, early and aggressive treatment should be administered. This accurate etiological diagnosis is important since immunsuppressive treatment may lead to further deterioration if an infection is the cause of vasculitis. Moreover, vasculitides and the need for immunsuppression represent a major risk factor for the development of common and opportunistic infections, including the highly prevalent SARS-CoV-2, which may additionally hinder the prognosis of these patients. Therefore, their prompt recognition and treatment are of utmost importance in this patient population to prevent excess morbidity and mortality.

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References

1. Jennette JC (2013) Overview of the 2012 revised International Chapel Hill Consensus Conference nomenclature of vasculitides. Clin Exp Nephrol 17:603–606. https://doi.org/10.1007/s10157-013-0869-6
2. Belizna CC, Hamidou MA, Levesque H, Guillevin L, Schonfeld Y (2009) Infection and vasculitis. Rheumatology (Oxford) 48:475–482. https://doi.org/10.1093/rheumatology/kep026
3. Nossent JC, Raymond W, Keen H, Preen DB, Inderjeeth CA (2020) Infection rates before and after diagnosis of IgA vasculitis in childhood: a population-wide study using non-exposed matched controls. J Rheumatol 47:424–430. https://doi.org/10.3899/jrheum.190110
4. Nossent J, Raymond W, Keen H, Inderjeeth C, Preen D (2020) Long-term risk of comorbidity after IgA vasculitis in childhood: a population-based cohort study. Rheumatol Ther 7:927–935. https://doi.org/10.1007/s40744-020-00239-y
5. Garcia-Porrua C, Gonzalez-Gay MA (1999) Bacterial infection presenting as cutaneous vasculitis in adults. Clin Exp Rheumatol 17:471–473
6. Cervi A, Kelly D, Alexopoulou I, Khalidi N (2017) ANCA-associated pauci-immune glomerulonephritis in a patient with bacterial endocarditis: a challenging clinical dilemma. Clin Nephrol Case Stud 5:32–37. https://doi.org/10.5414/CNCS109076
7. Riib C, Cohen P, Pagnozzi C, Mahr A, Arene JP, Puech X, Carl P, Kyndt X, Le Hillo C, Letellier P, Cordier JF, Guillevin L, French Vasculitis Study G (2010) Treatment of polyarteritis nodosa and microscopic polyangiitis without poor-prognosis factors: a prospective randomized study of one hundred twenty-four patients. Arthritis Rheum 62:1186–1197. https://doi.org/10.1002/art.27340
8. Kayria M, Chris O, Dhasmana DJ, Nilesh M, Hodson ME, Khin G, Diana B, Simmonds NJ (2017) Burkholderia cepacia
complex and limited cutaneous vasculitis in patients with cystic fibrosis: a case series. JRSM Open 8:2054270417692732. https://doi.org/10.1177/2054270417692732

9. Gadela NV, Drekolias D, Rizkallah A, Jacob J (2020) Infective endocarditis: a rare trigger of immunoglobulin a vasculitis in an adult. Cureus 12:e9892. https://doi.org/10.7759/cureus.9892

10. Pagnoux C, Cohen P, Guillevin L (2006) Vasculitides secondary to infections. Clin Exp Rheumatol 24:571-81

11. Farhadian JA, Castilla C, Shvartsbeyn M, Meehan SA, Neiman A, Pomeranz MK (2015) IgA vasculitis (Henoch-Schonlein purpura), Dermatol Online J. https://doi.org/10.5070/D32112029544

12. Agnello V, Chang RT, Kaplan LM (1992) A role for hepatitis C virus infection in type II cryoglobulinemia. N Engl J Med 327:1490–1495. https://doi.org/10.1056/NEJM199211193271204

13. Cacoub P, Terrier B (2009) Hepatitis B-related autoimmune manifestations. Rheum Dis Clin N Am 35:125–137. https://doi.org/10.1016/j.rdc.2009.03.006

14. Manuel A, Victorio T, Gomes C, Martins T, Dias Neto A (2015) Vasculitis: an unusual manifestation in an HIV-infected patient. Braz J Infect Dis 19:439–441. https://doi.org/10.1016/j.bjid.2015.04.006

15. Mani A, Mangia A, Kung Y, et al. (2016) Varicella zoster virus triggers the immunopathology of giant cell arteritis. Curr Opin Rheumatol 28:376–382. https://doi.org/10.1097/BOR.0000000000000292

16. Yag L, Xie H, Liu Z, Chen Y, Wang J, Zhang H, Ge Y, Hu W (2018) Risk factors for infectious complications of ANCA-associated vasculitis: a cohort study. BMC Nephrol 19:138. https://doi.org/10.1186/s12882-018-0933-2

17. Ohta T, Imanaga H, Oku S, Kusumoto H, Sugio Y, Tamiya S, Kishishita H, Ishii M (2012) Cutaneous polyarteritis nodosa induced by non-tuberculous mycobacterial infection. Clin Case Rep 7:1982–1983. https://doi.org/10.1002/ccr3.2414

18. Ohtsu T, Imanaga H, Oku S, Kusumoto H, Sugio Y, Tamiya S, Kudo Y, Ogawa H, Kikosaka K, Norose K, Ohno Y (2019) Toxoplasmosis-associated central nervous system vasculitis accompanied by multiple cerebral hemorrhages developing subsequent to cord blood transplantation. Rinsho Ketsueki 60:118–123. https://doi.org/10.1140/kensetsu.60.118

19. Renner R, Fleck A, Schubert S, Baerwald RC, Beer J, Schober R, Trimbos K, Holl-Ulrich K, Sticherling M (2008) Chronic urticaria and angioedema with concomitant eosinophilic vasculitis due to Trichodinae infection. Acta Derm Venereol 88:78–79. https://doi.org/10.2340/00015555-0331

20. de Boysson H, Martin Silva N, Comoz F, Boutemy J, Bienvenu AJ (2018) The contrasting epidemiology of granulomatosis with polyangiitis (Wegener’s) and microscopic polyangiitis. Rheumatology (Oxford) 51:926–931. https://doi.org/10.1093/rheumatology/ker454

21. Burgner D, Harnden A (2005) Kawasaki disease: what is the epidemiology telling us about the etiology? Int J Infect Dis 9:185–194. https://doi.org/10.1016/j.ijid.2005.03.002

22. Guillevin L, Cohen P, Gayraud M, Lhote F, Jarrousse B, Casassus P (1999) Churg-Strauss syndrome. Clinical study and long-term follow-up of 96 patients. Medicine (Baltimore) 78:26–37. https://doi.org/10.1097/00005792-199901000-00003

23. Hauser T, Mehr A, Metzler C, Coste J, Sommerstein R, Gross WL, Guillevin L, Hellmich B (2008) The leucotriene receptor antagonist montelukast and the risk of Churg-Strauss syndrome: a case–crossover study. Thorax 63:677–682. https://doi.org/10.1136/thx.2007.078825

24. Stegeman CA, Tervaert JW, de Jong PE, Kallenberg CG (1996) Polyarteritis nodosa associated with nontuberculous mycobacterial infection. Acta Derm Venereol 76:17–19. https://doi.org/10.23736/S00015555.96.00945-0

25. Watts RA, Mooney J, Skinner J, Scott DG, Macgregor AJ (2012) The contrasting epidemiology of granulomatosis with polyangiitis (Wegener’s) and microscopic polyangiitis. Rheumatology (Oxford) 51:926–931. https://doi.org/10.1093/rheumatology/ker454

26. Mossberg M, Segelmark M, Kahn R, Englund M, Mohammad AJ (2018) Epidemiology of primary systemic vasculitis in children: a population-based study from southern Sweden. Scand J Rheumatol 47:295–302. https://doi.org/10.1080/03009742.2017.1412497

27. Garcia-Porrúa C, Gonzalez-Gay MA, Lopez-Lazaro L (1999) Drug associated cutaneous vasculitis in adults in northwestern Spain. J Rheumatol 26:1942–1944

28. Bernstein ML, McCusker MM, Grant-Kels JM (2008) Cutaneous manifestations of cystic fibrosis. Pediatr Dermatol 25:150–157. https://doi.org/10.1111/j.1525-1470.2008.00620.x

29. Klimko A, Brandt A, Brustan MI, Balgrande M (2020) A case report of cystic fibrosis complication by Burkholderia cepacia and cutaneous vasculitis. Cureus 12:e8158. https://doi.org/10.7759/cureus.8158

30. Betti C, Camozzi P, Gennaro V, Bianchetti MG, Scoglio M, Simonetti GD, Milani GP, Lava SG, Ferrarini A (2021) Atypical bacterial pathogens and small-vessel leukocytoclastic vasculitis of the skin in children: systematic literature review. Pathogens. https://doi.org/10.3390/pathogens10010031

31. Mah A, Guillevin L, Poissonnet M, Ayme S (2004) Prevalence of polyarteritis nodosa, microscopic polyangiitis, Wegener’s granulomatosis, and Churg-Strauss syndrome in a French urban multiethnic population in 2000: a capture-recapture estimate. Arthritis Rheum 51:92–99. https://doi.org/10.1002/art.20077

32. Imanishi H, Tsuruta M, Oshino T, Sowa J, Mizuno N, Nakagawa K, Ishii M (2012) Cutaneous polyarteritis nodosa induced by Mycobacterium tuberculosis. J Dermatol 39:738–739. https://doi.org/10.1111/j.1346-8138.2011.01398.x

33. Stubbs A, Kowal C, Askari A, Anthony DD, Mattar M (2018) Achieving sustained viral remission in patients with chronic HCV infection and cryoglobulinemic vasculitis does not always correlate with normalization of the serologic markers. J Clin Immunol 9:562. https://doi.org/10.4172/2155-9899.1000562

34. Zignego AL, Marri S, Gragnani L (2021) Impact of direct acting antivirals on hepatitis c virus-related cryoglobulinemic syndrome. Minerva Gastroenterol (Torino). https://doi.org/10.23736/S2724-5985.21.02848-8

35. Mazzaro C, Mauro E, Ermacora A, Doretto P, Fumagalli S, Tonizzo M, Toffoliutti F, Gattei V (2021) Hepatitis C virus-related cryoglobulinemic vasculitis. Minerva Med 112:175–187. https://doi.org/10.20373/50026-4806.20.07120-7

36. Vega LE, Espinoza LR (2020) Vasculitides in HIV infection. Curr Rheumatol Rep 22:60. https://doi.org/10.1007/s11926-020-00945-0

37. Bennett BS, Mikaberidze N, Ahmad M (2019) A case of dolutegravir-induced cutaneous small vessel vasculitis. AIDS 33:1803–1804. https://doi.org/10.1097/QAD.0000000000002262
41. Pillay B, Ramdial PK, Naidoo DP (2015) HIV-associated large-vessel vasculopathy: a review of the current and emerging clinicopathological spectrum in vascular surgical practice. Cardiovasc J Afr 26:70–81. https://doi.org/10.5830/CVJA-2015-017

42. Ferfar Y, Savelly L, Comarmond C, Sadaghihlooo N, Garrido M, Domont F, Volantin MA, Pourcher-Martinez V, Cluzel P, Fourot P, Chiche L, Gaudric J, Koskas F, Cabou P, Saadoun D (2018) Large-vessel vasculitis in human immunodeficiency virus-infected patients. J Vasc Surg 67:1501–1511. https://doi.org/10.1016/j.jvs.2017.08.099

43. Theofilis P, Sagris M, Okkonoumou E, Antonopoulos AS, Siasos G, Tsoutsis C, Tousoulis D (2021) Inflammatory mechanisms contributing to endothelial dysfunction. Biomedicines. https://doi.org/10.3390/biomedicines9070781

44. Sagris M, Theofilis P, Antonopoulos AS, Tsoutsis C, Okkonoumou E, Antoniades C, Crea F, Kaski JC, Tousoulis D (2021) Inflammatory mechanisms in COVID-19 and atherosclerosis: current pharmaceutical perspectives. Int J Mol Sci. https://doi.org/10.3390/ijms22126607

45. Farooq H, Aemaz Ur Rehman M, Asmar A, Asif S, Mushtaq A, Sagris M, Theofilis P, Antonopoulos AS, Tsioufis C, Oikonomou E, Theofilis P, Sagris M, Oikonomou E, Antonopoulos AS, Siasos G, Tsoutsis C, Tousoulis D (2021) Inflammatory mechanisms contributing to endothelial dysfunction. Biomedicines. https://doi.org/10.3390/biomedicines9070781

46. Jiao FY (2020) Kawasaki disease: a new manifestation of viral myocarditis and systemic vasculitis—systematic review of its pathogenesis and treatment. Front Pediatr 8:626182. https://doi.org/10.3389/fped.2020.626182

47. Villacis-Nunez DS, Hashemi S, Nelson MC, Flanagan E, Thakral A, Rodriguez F 3rd, Jaggi P, Oster ME, Prahalad S, Rouster-Stevens KA (2021) Giant coronary aneurysms in multisystem inflammatory syndrome in children associated with SARS-CoV-2 infection. JACC Case Rep 3:1499–1508. https://doi.org/10.1016/j.jaccr.2021.06.043

48. Sharma C, Ganigara M, Galeotti C, Burns J, Berganza FM, Hayes DA, Singh-Grewal D, Bharath S, Sujan J, Bayry J (2021) Multisystem inflammatory syndrome in children and Kawasaki disease: a critical comparison. Nat Rev Rheumatol 17:731–748. https://doi.org/10.1038/s41584-021-00709-9

49. Patel P, DeCuir J, Abrams J, Campbell AP, Godfred-Cato S, Belay ED (2021) Clinical characteristics of multisystem inflammatory syndrome in adults: a systematic review. JAMA Netw Open 4:e2126456. https://doi.org/10.1001/jamanetworkopen.2021.26456

50. Fabi M, Filice E, Biagi C, Andreozzi L, Palleri D, Mattesini BE, Rizzello A, Gabrielli L, Ghizzi C, Di Luca D, Caramelli F, De Fanti A, Lanari M (2021) Multisystem inflammatory syndrome following SARS-CoV-2 infection in children: one year after the onset of the pandemic in a high-incidence area. Viruses. https://doi.org/10.3390/v13102022

51. Kharkar V, Vishwanath T, Mahajan S, Joshi R, Gole P (2021) Asymmetrical cutaneous vasculitis following COVID-19 vaccination with unusual eosinophil preponderance. Clin Exp Dermatol. https://doi.org/10.1111/ced.14797

52. Cavalli G, Colafrancesco S, De Luca G, Rizzo N, Priori R, Conti F, Dagna L (2021) Cutaneous vasculitis following COVID-19 vaccination. Lancet Rheumatol 3:e743–e744. https://doi.org/10.1016/S2665-9913(21)00309-X

53. Feghali EJ, Zafar M, Abid S, Santoriello D, Mehta S (2021) Delayed-onset cutaneous vasculitis changes in COVID-19 survivors with positive SARS-CoV-2 PCR in skin biopsy. BMJ Case Rep. https://doi.org/10.1136/bcr-2021-26456

54. Bennett K (2021) Pathogenesis of COVID-19 in children. Zhongguo Dang Dai Er Ke Za Zhi Med 33:1389–1401. https://doi.org/10.1016/j.zdem.2021.101549

55. Vernant JC, Smadja D, Deforge-Lasseur C, Cabre P, Buisson G, Neisson-Vernant C, Desgranges C (1994) Viral myocarditis and systemic vasculitis—systematic review in adults with unusual eosinophil preponderance. Clin Exp Dermatol. https://doi.org/10.1111/j.1365-4632.1994.tb07814.x

56. Feghali EJ, Zafar M, Abid S, Santoriello D, Mehta S (2021) Delayed-onset cutaneous vasculitis changes in COVID-19 survivors with positive SARS-CoV-2 PCR in skin biopsy. BMJ Case Rep. https://doi.org/10.1136/bcr-2021-26456

57. McLaughlin SK, Lawrence L, Adler J, Mehta H (2020) Henoch-Schönlein purpura-associated hemorrhagic shock after secondary norovirus infection. Cureus 12:e11653. https://doi.org/10.7759/cureus.11653

58. Wolfe RM, Peacock JE Jr (2017) Pneumocystis pneumonia and the rheumatologist: which patients are at risk and how can PCP be prevented? Curr Rheumatol Rep 19:35. https://doi.org/10.1007/s11926-017-0664-6

59. Lhote F (2004) Systemic vasculitis during parasitosis. Presse Med 33:1389–1401. https://doi.org/10.1016/j.pmed.2004.09.003

60. Rodriguez-Pla A, Stone JH (2006) Vasculitis and systemic infections. Curr Opin Rheumatol 18:39–47. https://doi.org/10.1097/01.bor.0000197999.58073.2e
72. Manders SM (1998) Toxin-mediated streptococcal and staphylococcal disease. J Am Acad Dermatol 39:383–398. https://doi.org/10.1016/s1027-7837(98)00278-2
73. Xu SX, McCormick J (2012) Staphylococcal superantigens in colonization and disease. Front Cell Infect Microbiol 2:52. https://doi.org/10.3389/fcimb.2012.00052
74. Wilde B, van Paassen P, Witzke O, Tervaert JWC (2011) New pathophysiological insights and treatment of ANCA-associated vasculitis. Kidney Int 79:599–612. https://doi.org/10.1038/ki.2010.472
75. Millikan LE, Flynn TC (1999) Infectious etiologies of cutaneous vasculitis. Clin Dermatol 17:509–514. https://doi.org/10.1016/S0738-081X(99)00061-9
76. Couser WG (2012) Basic and translational concepts of immune-mediated glomerular diseases. J Am Soc Nephrol 23:381–399. https://doi.org/10.1681/ASN.2011103030
77. Xiao H, Schreiber A, Heeringa P, Falk RJ, Jennette JC (2007) Alternative complement pathway in the pathogenesis of disease mediated by anti-neutrophil cytoplasmic autoantibodies. Am J Pathol 170:52–64. https://doi.org/10.2353/ajpath.2007.060573
78. Wu EY, McInnis EA, Boyer-Suavet S, Mendoza CE, Aybar LT, Kennedy KB, Poulton CJ, Henderson CD, Hu Y, Hogan SL, Hu P, Xiao H, Nachman PH, Jennette JC, Falk RJ, Bunch DO (2019) Measuring circulating complement activation products in myeloperoxidase- and proteinase 3-antineutrophil cytoplasmic antibody-associated vasculitis. Arthritis Rheumatol 71:1894–1903. https://doi.org/10.1002/art.41011
79. Onuora S (2021) Avacopan offers alternative to steroids for severe infections in patients with ANCA-associated vasculitis treated with rituximab. Rheumatology (Oxford) 61:205–212. https://doi.org/10.1093/rheumatology/keab293
80. Ladner B, Windpess M, Kroll M, Steiner M, Riedl R, Hebesberger C, Ursli M, Z le H, Lottke H, Antlinger M, Cejda K, Gaukler P, Wiesholzer M, Saemmann M, Rosenkranz AR, Eller K, Kronbichler A, G eneral Concepts and Pathophysiology of ANCA-Associated Vasculitis. Am J Pathol 170:52–64. https://doi.org/10.1128/CP204053
81. Weyand CM, Goronzy JJ (2014) Giant-cell arteritis and polyarteritis: relationship to ANCA-associated vasculitis. Curr Opin Rheumatol 26:587–590. https://doi.org/10.1097/BOR.0000000000000348
82. Matraiah EH, Olsiaka N, Philips M, Waalbaum D, Dospinescu P, Fluck N, Basu N, Kiddir D (2018) Late-onset Pneumocystis jirovecii pneumonia (PJP) in patients with ANCA-associated vasculitis. Clin Rheumatol 37:1991–1996. https://doi.org/10.1007/s10067-018-4155-6
83. Thery-Casari C, Euvrard R, Mainbourg S, Durupt S, Reynaud Q, Durieu I, Belot A, Lobbes H, Cabrera N, Lega JC (2020) Severe infections in patients with anti-neutrophil cytoplasmic antibody-associated vasculitides receiving rituximab: a meta-analysis. Autoimmun Rev 19:102505. https://doi.org/10.1016/j.autrev.2020.102505
84. Kronbichler A, Kerschbaum J, Gopaluni S, Tieu J, Alberici F, Jones RB, Smith RM, Bacon PA (1997) Controlled trial of pulse versus continuous prednisolone and cyclophosphamide in the treatment of systemic vasculitis. QJM 90:401–409. https://doi.org/10.1002/art.41728
85. Sattui SE, Conway R, Putman MS, Seet AM, Gianfrancesco MA, Beins K, Hill C, Liew JW, Sirotich E, Sufka P, Wallace ZS, Yazdany J, Machado PM, Robinson PC, Alliance C-GR (2020) Characteristics associated with hospitalisation for COVID-19 in people with rheumatic disease: data from the COVID-19 Global Rheumatology Alliance physician-reported registry. Ann Rheum Dis 79:859–866. https://doi.org/10.1136/annrheumdis-2020-217871
86. Gianfrancesco M, Hrych KL, Al-Adey S, Carmona L, Danila MI, Gosses L, Izadi Z, Jacobsbohn L, Katz P, Lawson-Tovey S, Mateus EF, Rush S, Smajlik G, Simard J, Strangfeld A, Trupin L, Wysham KD, Bhana S, Costello W, Grainger R, Haussmann JS, Sattui SE, Conway R, Putman MS, Seet AM, Gianfrancesco MA, Beins K, Hill C, Liew J, Maldonado FN, Mariz HA, de Sousa Studart MI, Gossec L, Izadi Z, Jacobsbohn L, Katz P, Lawson-Tovey S, Mateus EF, Rush S, Smajlik G, Simard J, Strangfeld A, Trupin L, Wysham KD, Bhana S, Costello W, Grainger R, Haussmann JS, Sattui SE, Conway R, Putman MS, Seet AM, Gianfrancesco MA, Beins K, Hill C, Liew J, Mackie SL, Mehta P, Neill L, Gomez G, Salinas MIH, Maldonado FN, Mariz HA, de Sousa Studart SA, Araujo NC, Knight A, Rozza D, Quartuccio L, Samson M, Bally S, Maria AT, Chazerain P, Hasseli R, Muller-Ladner U, Hoyer BF, Volf R, Torres RP, Luis M, Ribeiro SLE, Al-Emadi S, Sparks JA, Hsu TY, D’Silva KM, Patel NJ, Wise L, Gilbert E,
Almada MV, Duarte-Garcia A, Ugarte-Gil M, Jacobsohn L, Izadi Z, Strangfeld A, Mateus EF, Hyrich KL, Gossec L, Carmona L, Lawson-Tovey S, Kearsley-Fleet L, Schaefer M, Sirotich E, Hausmann JS, Sufka P, Bhana S, Liew JW, Grainger R, Machado PM, Wallace ZS, Yazdany J, Robinson PC, Global Rheumatology A (2021) Outcomes of COVID-19 in patients with primary systemic vasculitis or polymyalgia rheumatica from the COVID-19 Global Rheumatology Alliance physician registry: a retrospective cohort study. Lancet Rheumatol 3:e855–e864. https://doi.org/10.1016/S2665-9913(21)00316-7

98. Strangfeld A, Schafer M, Gianfrancesco MA, Lawson-Tovey S, Liew JW, Ljung L, Mateus EF, Richez C, Santos MJ, Schmajuk G, Scire CA, Sirotich E, Sparks JA, Sufka P, Thomas T, Trupin L, Wallace ZS, Al-Adely S, Bachiller-Corral J, Bhana S, Cacoub P, Carmona L, Costello R, Costello W, Gossec L, Grainger R, Hachulla E, Hasseli R, Hausmann JS, Hyrich KL, Izadi Z, Jacobsohn L, Katz P, Kearsley-Fleet L, Robinson PC, Yazdany J, Machado PM, Alliance C-GR (2021) Factors associated with COVID-19-related death in people with rheumatic diseases: results from the COVID-19 Global Rheumatology Alliance-patient-reported registry. Ann Rheum Dis 80:930–942. https://doi.org/10.1136/annrheumdis-2021-221490

99. Ghosh J, Kant S, Kastner IV, Geetha D (2021) Bamlanivimab decreases severe outcomes of SARS-CoV-2 infection in ANCA vasculitis patients. Kidney Int Rep. https://doi.org/10.1016/j.ekir.2021.12.010

100. Floyd L, Elsayed ME, Seibt T, von Bergwelt-Baildon A, Seo P, Antiochos B, Kant S, Morris A, Dhaygude A, Schonermarck U, Geetha D (2021) SARS-CoV-2 vaccine response in ANCA associated vasculitis patients. Kidney Int Rep. https://doi.org/10.1016/j.ekir.2021.12.004

101. Kant S, Azar A, Geetha D (2021) Antibody response to COVID-19 booster vaccine in rituximab-treated patients with anti-neutrophil cytoplasmic antibody-associated vasculitis. Kidney Int. https://doi.org/10.1016/j.kint.2021.11.012

102. Machado PM, Lawson-Tovey S, Strangfeld A, Mateus EF, Hyrich KL, Gossec L, Carmona L, Rodrigues A, Raffeiner B, Duarte C, Hachulla E, Veillard E, Strakova E, Burmester GR, Yardimci GK, Gomez-Puerta JA, Zepa J, Kearsley-Fleet L, Trefond L, Cunha M, Mosca M, Cornalba M, Soubrier M, Roux N, Brocq O, Durez P, Conway R, Goulonok T, Bijlsma JW, McInnes IB, Mariette X (2021) Safety of vaccination against SARS-CoV-2 in people with rheumatic and musculoskeletal diseases: results from the EULAR Coronavirus Vaccine (COVAX) physician-reported registry. Ann Rheum Dis. https://doi.org/10.1136/annrheumdis-2021-221490

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