Musculoskeletal Manifestations of COVID-19: Currently Described Clinical Symptoms and Multimodality Imaging Findings

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SA-CME LEARNING OBJECTIVES

After completing this journal-based SA-CME activity, participants will be able to:

■ Discuss the pathophysiologic mechanisms associated with the most commonly seen MSK manifestations of COVID-19.

■ Describe imaging findings and patterns of disease involving the common COVID-19 MSK manifestations at various modalities.

■ Recognize MSK MRI findings following COVID-19 vaccine administration, as well as abnormalities that can be seen in patients with persistent pain after receiving the vaccine.

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COVID-19, the clinical syndrome produced by infection with SARS-CoV-2, can result in multisystem organ dysfunction, including respiratory failure and hypercoagulability, which can lead to critical illness and death. Musculoskeletal (MSK) manifestations of COVID-19 are common but have been relatively underreported, possibly because of the severity of manifestations in other organ systems. Additionally, patients who have undergone sedation and who are critically ill are often unable to alert clinicians of their MSK symptoms. Furthermore, some therapeutic measures such as medications and vaccinations can worsen existing MSK symptoms or cause additional symptoms. Symptoms may persist or occur months after the initial infection, known as post-COVID condition or long COVID. As the global experience with COVID-19 and the vaccination effort increases, certain patterns of MSK disease involving the bones, muscles, peripheral nerves, blood vessels, and joints have emerged, many of which are likely related to a hyper-inflammatory host response, prothrombotic state, or therapeutic efforts rather than direct viral toxicity. Imaging findings for various COVID-19–related MSK pathologic conditions across a variety of modalities are being recognized, which can be helpful for diagnosis, treatment guidance, and follow-up.

The online slide presentation from the RSNA Annual Meeting is available for this article.

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Introduction

COVID-19, produced by infection with SARS-CoV-2, is a novel disease first described in patients in Wuhan, China, in December 2019. As of mid-May 2022, more than 520 million cases and 6.2 million deaths have been reported worldwide (1). Initial descriptions of this disease focused on respiratory manifestations and hematologic disorders, which result in the greatest morbidity and mortality, although infection often involves numerous organ systems, resulting in multisystem organ failure and ultimately death (2).

Musculoskeletal (MSK) manifestations are commonly among the earliest presenting symptoms of COVID-19 but have been much less widely reported and may be underrecognized for several reasons. Acute MSK symptoms, which occur within 4 weeks of infection, including fatigue and myalgia, are nonspecific (3). Moreover, patients who are critically ill and often undergo sedation and intubation may be unable to report MSK symptoms. Finally, other MSK symptoms may manifest after the initial infection has resolved, either in the early post-acute period or in the weeks to months following the original infection, often referred to as post-COVID condition or long COVID. In a study by Bakilan et al (4), 72% of patients with post-acute

COVID-19 reported fatigue, while spine pain was present in 71% of patients and myalgias and arthralgias were noted in 61% and 44% of patients, respectively. As the global experience with COVID-19 increases, it is becoming more widely recognized that MSK symptoms, many of which have described imaging findings, can lead to prolonged disability after recovery from the initial infection (5). Furthermore, COVID-19 vaccinations have resulted in rare MSK-related complications, which have additional imaging findings.

In this article, we review the current understanding of the pathophysiology of COVID-19 and the rare vaccine-related complications, particularly as they relate to MSK manifestations, as well as currently available descriptions of imaging findings in these conditions.

Pathophysiology of SARS-CoV-2 Infection

SARS-CoV-2 is an enveloped single-stranded positive-sense messenger RNA (mRNA) virus from the same family of coronaviruses as severe acute respiratory syndrome coronavirus 1 (SARS-CoV-1) and Middle East respiratory syndrome coronavirus (MERS-CoV) that cause severe acute respiratory syndrome (SARS) and Middle East respiratory syndrome (MERS), respectively. SARS-CoV-1 and SARS-CoV-2 have a high degree of genetic and conformational homology and both target the angiotensin-converting enzyme 2 (ACE2) receptor. In the MSK system, skeletal muscle, adipocytes, and endothe-

lial cells in some tissues express ACE2 receptors, representing potential targets for SARS-CoV-2 infection, which may explain some MSK manifestations of disease (6).

Three main pathophysiologic pathways have been proposed to explain the effects of COVID-19 in the MSK system, including the cytokine storm, development of a prothrombotic state, and autoimmunity. The cytokine storm is an inflammatory cascade triggered by the virus that causes elevations in many cytokine levels. Elevated interleukin 6 (IL-6) levels, in particular, have correlated well with more severe disease (7). There is debate in the literature about the term *cytokine storm*, since the circulating levels of many cytokines may be only modestly elevated despite an inflammatory dysregulation, similar to that in some patients with sepsis. Therefore, some authors have suggested that the term *systemic inflammatory response* more accurately describes this phenomenon (8).

Platelet hyperreactivity, which could result from direct viral invasion or indirect activation by cytokine release, and activation of the complement system may cause further cytokine release, stimulating the coagulation cascade and suppressing fibrinolysis. Additionally, patients with severe COVID-19 may have limited mobility, which promotes vascular stasis, platelet and erythrocyte aggregation, and thrombosis (9).

Patients with COVID-19 have developed several autoimmune conditions, such as rheumatoid arthritis (RA), psoriatic arthritis, and systemic lupus erythematosus, after the onset of infection (10). Up to 45% of COVID-19 patients exhibit at least one circulating autoantibody. Higher concentrations of autoantibodies often result in more severe symptoms, suggesting that autoimmunity plays a role in the pathogenesis of COVID-19. SARS-CoV-2 has several epitopes that cross-react with host antigens and could result in autoimmune conditions. For example, Lucchese and Flöel (11) showed cross-reactivity of SARS-CoV-2 epitopes with those on heat shock proteins 90 and 60, which could contribute to the development of Guillain-Barré syndrome (GBS). Autoimmunity due to SARS-CoV-2 infection may also be related to superantigen reactivity (12).

Although the specific mechanisms resulting in clinical symptoms in COVID-19 are being assessed, a few common pathways, including systemic inflammatory dysregulation, autoimmunity, and hypercoagulability, often occur together to produce end-organ damage in a variety of tissues (Fig 1).

COVID-19 in MSK System

Within the MSK system, COVID-19 may affect bones, muscles, the coagulation pathway, periph-
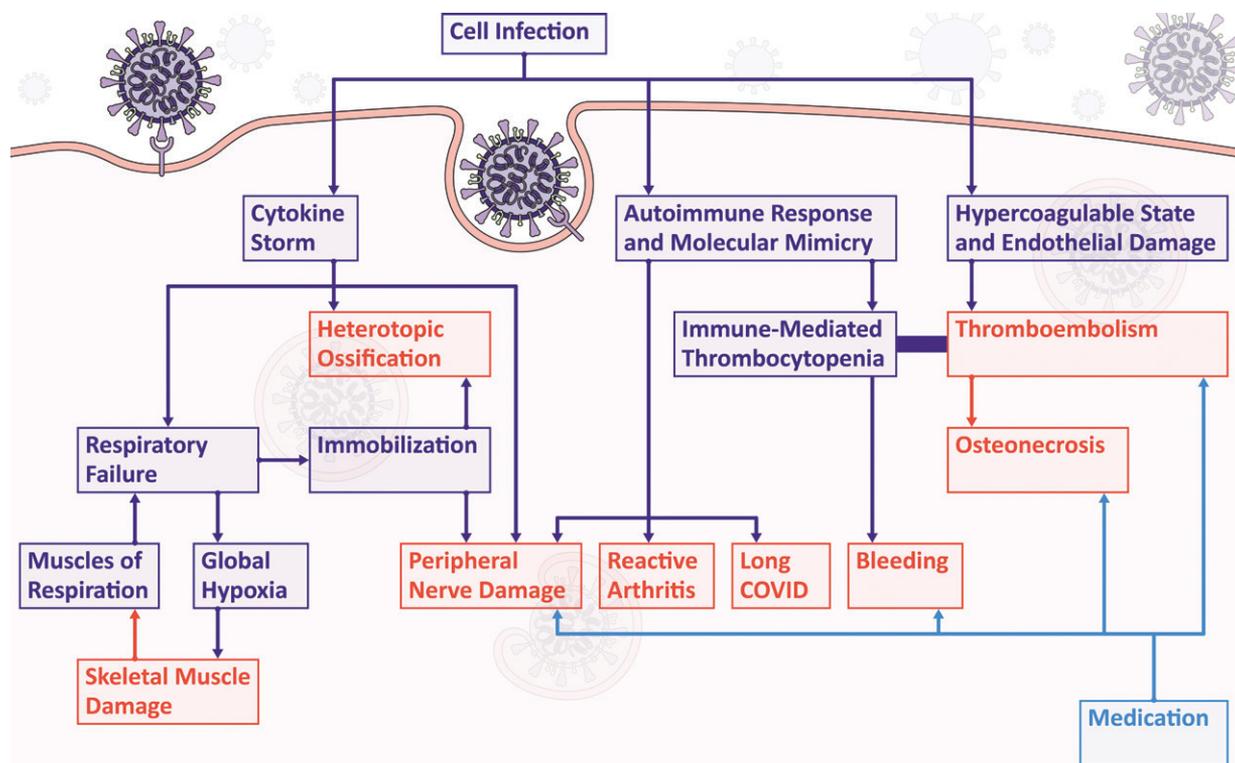
Figure 1.   Diagram shows the pathogenesis of SARS-CoV-2 infection after viral cell entry. Three main processes—the cytokine storm, an autoimmune response, and hypercoagulability—lead to a cascade of events contributing to many of the most common MSK clinical conditions (items in red). Treatments such as medications, and vaccinations can also contribute to the pathogenesis of various conditions.

eral nerves, and joints. Additionally, patients with long COVID or those who have been treated or vaccinated can present with MSK symptoms. While the causes of these conditions are complex and likely multifactorial, some themes have emerged as our understanding evolves.

Osseous Manifestations

COVID-19 patients may present with articular or periarticular pain, which can be secondary to osteonecrosis (ON). Cortical bone is a potential site of direct infection by SARS-CoV-2 owing to its expression of ACE2 receptors (13). ON is a well-described condition associated with the original SARS, reported in 5%–58% of patients. Proposed mechanisms include corticosteroid administration, hypercoagulability, vascular inflammation (including endothelial inflammation and perivascular leukocyte aggregation), and bone resorption by stimulation of ACE2 receptors (14).

Corticosteroid therapy, likely the leading cause of ON, is administered to severely and critically ill patients who require ventilation to reduce morbidity and mortality and may be used in high doses over prolonged periods. The risk of ON was greatly increased in those patients with SARS who received higher doses (cumulative dose greater than or equal to the equivalent of 4000 mg methylprednisone and peak dose the equiva-

lent of 200 mg methylprednisone) for 1 week or more (15). Other risk factors include male sex, use of multiple types of corticosteroids, alcohol or tobacco use, and cardiovascular and/or cerebrovascular disease. The most common sites of ON in patients with SARS and COVID-19 are the femoral head, knee, humeral head, talus, and calcaneus. Although the precise cause of steroid-induced ON is unknown and probably multifactorial, it likely involves osteoblastic suppression and osteocyte apoptosis, leading to bone resorption, along with the development of microthrombi that result in decreased perfusion and intraosseous adipogenesis. This increases intramedullary pressure and may cause vascular occlusion and venous stasis (13). Agarwala et al (16) reported the development of ON in COVID-19 patients with a lower steroid dose and over a shorter time compared with patients without COVID-19. There are reports that symptoms of hemoglobinopathies, such as acute chest syndrome in sickle cell disease, may worsen after COVID-19 infection, and some patients may develop ON. Sheha et al (17) reported a case of a patient who was discovered to have sickle cell trait after developing ON during COVID-19 infection.

The imaging findings of periarticular ON in COVID-19 patients are similar to those seen in patients with other conditions. Many severely ill

Figure 2. ON of the humeral heads in a 62-year-old woman with a history of sickle cell disease and post–CO-VID-19 condition with progressive shortness of breath and corticosteroid treatment. Axial CT image (bone window) of the chest shows subchondral serpentine lucency, adjacent sclerosis (arrows), and subchondral plate irregularity involving both humeral heads, especially on the left. The humeral heads appeared normal at a prior CT examination 1.5 years earlier (see supplemental online presentation).
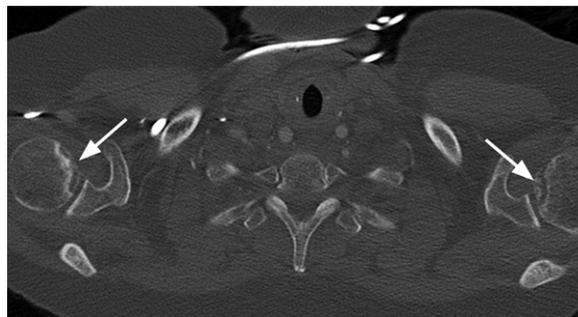

Figure 3. Multifocal ON of the foot in a 66-year-old nondiabetic woman who presented with COVID toes. **(A)** Sagittal T1-weighted non–fat-suppressed MR image of the right second toe shows multifocal serpentine areas of dark signal intensity (arrows), most pronounced in the metatarsal head. **(B)** Sagittal T2-weighted fat-suppressed MR image of the region shows corresponding areas of subchondral marrow edema (arrows), which are confluent in the phalanges, with associated periosteal edema and digital soft-tissue edema. The skin dorsal to the middle and distal phalanges and over the distal phalangeal distal tuft is thinned, corresponding to cutaneous excoriation. **(C, D)** Axial **(C)** and sagittal **(D)** T1-weighted fat-suppressed postcontrast MR images show nonenhancing central areas of necrosis, with peripheral enhancement (solid arrows) reflecting reparative change. There is extensive great toe soft-tissue enhancement (dashed arrows) corresponding to the edema and rash seen in COVID toes.

COVID-19 patients undergo periodic chest CT and abdominal CT examinations for respiratory and gastrointestinal symptoms, which may help detect radiographically occult ON of the humeral and femoral heads (17) (Fig 2). MRI remains the most sensitive modality for detecting occult ON with stage-related characteristic imaging findings (16).

COVID toes, also known as chilblainlike or perniolike lesions, are localized acral cutaneous erythematous eruptions commonly involving the toes more often than the fingers. This is most commonly seen in teens and young adults, especially in immunocompetent patients or those with mild COVID-19 symptoms. Its cause is unknown. However, several authors have suggested vascular and immunologic causes, including vasospasm, perivascular lymphocytic aggregation involving small dermal vessels, endothelial damage, and fibrin microthrombi (18). These lesions are usually evident at visual inspection without the need for imaging. However, COVID toes may be associated with ON of the small bones of the feet, diagnosed at MRI, in patients without other common causes for ON (Fig 3).

There are several case reports of heterotopic ossification (HO) in critically ill COVID-19 patients, which may cause joint pain. Stoira et al (19) reported a prevalence of 19.2% (10 of 52 patients) in the largest case series to date. According to current reports, the hips and shoulders have been most commonly involved, followed by the elbows, similar to patients who develop HO secondary to other conditions (19). Prolonged immobilization, especially in patients who have required ventilation, is the biggest factor contributing to the development of HO. However, systemic inflammation seen in COVID-19 patients may upregulate the IL-6/tumor necrosis factor α (TNF-α) pathway and stimulate mesenchymal cells to release prostaglandin E2, which have been associated with HO development (20).

The early imaging findings of HO are better depicted at CT than radiography, with peripheral soft-tissue mineralization gradually maturing to cortical bone with internal cancellous bone,
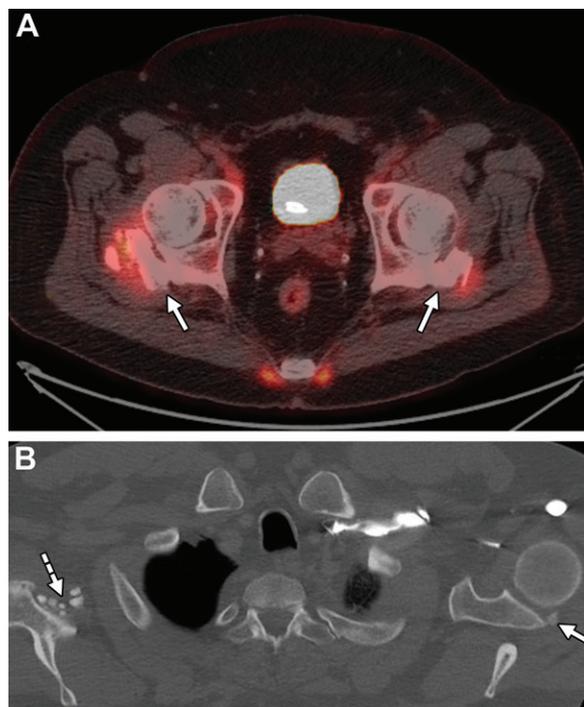
Figure 4. HO in two patients. **(A)** Axial fused PET/CT image through the hips in a 55-year-old woman with prolonged hospitalization for COVID-19 and progressive hip stiffness shows extensive bulky HO (arrows) at the posterolateral aspect of both acetabula that is partially adherent to the underlying bone and mildly hypermetabolic. **(B)** Axial CT image (bone window) of the chest at the level of the glenohumeral joints in a 54-year-old man with a history of COVID-19 (hospitalized for 6 weeks) and with left shoulder stiffness shows bilateral periarticular ossifications. On the right, there is incompletely assessed glenohumeral osteoarthritis with clustered anterior joint recess intra-articular bodies that are separate from the glenoid rim (dashed arrow). On the left, the ossification is well corticated and partially adherent to the posterior glenoid rim (solid arrow), consistent with mild HO. No signs of left glenohumeral osteoarthritis are depicted. Note the right apical pneumothorax related to the patient's underlying pulmonary disease.

which subsequently may attach to the underlying bone surface (20) (Fig 4). Initial MRI findings may be confusing with avidly enhancing extensive soft-tissue edema and distortion. As HO matures, the peripheral low-signal-intensity rim of calcification confirms the diagnosis (21).

Muscle Manifestations

COVID-19 may manifest with myalgias and fatigue unrelated to disease severity. Severe muscle injury can be associated with multisystem organ failure. This includes myoglobinuria in the setting of rhabdomyolysis, which can lead to renal insufficiency, and involvement of respiratory muscles, which can worsen dyspnea related to respiratory failure (22,23). These complications are more common in patients who are older and critically ill. The cause is likely multifactorial, including immune-mediated damage, intensive care unit–acquired weakness, toxic myopathy, and possibly

direct viral damage, with certain factors playing a larger role in the development of muscle injury in particular patients. COVID-19–related muscle pathologic conditions can be divided into four categories—myalgias, myositis, myonecrosis, and rhabdomyolysis—which can help imaging assessment. Noninflammatory myalgias are generally self-limited and treated conservatively. If a patient with myalgias undergoes imaging with CT or MRI, the muscle should look normal, without fascial thickening, fluid, or enhancement (24).

Myositis, a true inflammation of skeletal muscle, can occur in a variety of conditions, including SARS-CoV-2 infection. Serum muscle-specific markers can be transiently elevated. MR images may show areas of skeletal muscle and fascial and subcutaneous edema with hyperintense signal with fluid-sensitive sequences and postcontrast enhancement (25) (Fig 5). Although CT images may also show muscle thickening and effacement of intramuscular fat and fascial planes, MR images can better depict muscle edema, fascial stranding, and postcontrast enhancement.

Myonecrosis has several causes, including radiation therapy, diabetes mellitus, immobilization, exercise, medications (eg, statins), and therapeutic ablation (25). There may be mild transient elevation of serum creatine kinase levels. However, urine myoglobin levels are normal. Myonecrosis can result in substantial pain, and patients are treated supportively. MRI and CT show similar findings, although MRI is more sensitive for helping detect areas of myonecrosis. Two MRI patterns have been described: type 1 myonecrosis reflects potentially reversible muscle ischemia, and type 2 myonecrosis results from irreversible muscle infarction. In type 1 myonecrosis, the MRI findings are similar to those of myositis, with areas of diffuse muscle and fascial edema with fluid-sensitive sequences and postcontrast enhancement. In type 2 changes, there are nonenhancing intramuscular areas of variable sizes, often with thin peripheral enhancement (Fig 6). Frequently observed is a stipple sign, with linear or curvilinear foci of enhancement within the area of necrosis on long-axis images that have a dotlike appearance in cross-section planes, possibly representing residual viable myofibers or inflamed crossing vessels (26).

Rhabdomyolysis represents significant muscle injury and possibly myonecrosis leading to more pronounced, sustained elevations of serum creatine kinase levels and myoglobinuria, which can result in acute renal injury. In COVID-19 patients, rhabdomyolysis is often symmetric with a proximal lower limb predominance, leading to profound weakness (23). The diagnosis is made clinically, and imaging may help assess the location

Figure 5.   COVID-19–related myositis in a 59-year-old nondiabetic woman who presented with burning bilateral foot pain and swelling. The serum C-reactive protein concentration was elevated to 197 mg/dL, consistent with the inflammatory state, although the serum creatine kinase level remained normal. Axial T2-weighted fat-suppressed MR image **(A)** of the right forefoot shows extensive diffuse intrinsic muscle edema, with extensive enhancement seen in the same region on the axial postgadolinium-enhanced T1-weighted fat-suppressed MR image **(B)**. The findings were symmetric with those of the contralateral left forefoot (see supplemental online presentation).
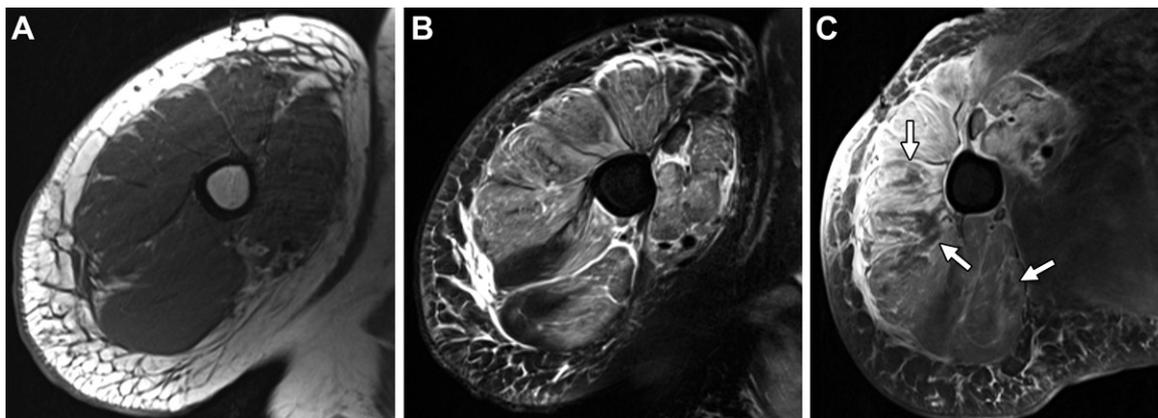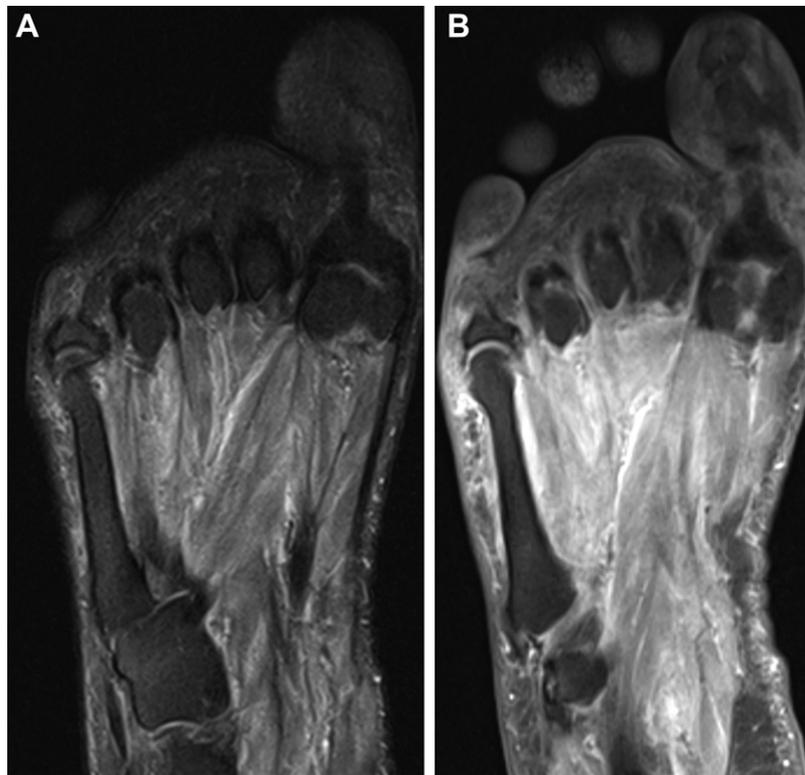

Figure 6.   Myonecrosis in a 44-year-old man with a history of COVID-19 acute respiratory distress syndrome and right shoulder and arm pain and swelling. The serum creatine kinase level briefly peaked at 645 units/L (normal, 0–223 units/L) and quickly normalized. **(A)** Axial T1-weighted non–fat-suppressed MR image of the right upper arm shows mild subcutaneous reticular stranding extending to the muscular fascia without muscle atrophy or fatty infiltration. **(B)** Axial T2-weighted fat-suppressed MR image of the same area shows extensive diffuse muscle edema with some focal sparing of the adjacent anterolateral triceps and posterior deltoid muscles. There is circumferential deep and superficial fascial and subcutaneous edema. **(C)** Axial T1-weighted fat-suppressed postcontrast MR image of the same area shows extensive muscle and fascial enhancement, consistent with myositis, with scattered small areas of nonenhancement, consistent with focal type 2 myonecrosis (arrows), surrounded by rims of peripherally enhancing muscle.

and degree of muscle injury. The MRI findings are similar to those of myositis, although there may be areas of nonenhancing type 2 myonecrosis (26).

Joint Manifestations

Patients with COVID-19 often present with arthralgias. When there is an identifiable cause, synovitis related to a primary postviral inflammatory arthritis or other rheumatologic conditions such as RA, systemic lupus erythematosus, or

psoriatic arthritis may occur in addition to ON and HO as previously mentioned (10).

Post–COVID-19 inflammatory arthritis is an aseptic inflammatory arthropathy likely related to the host immune response. Many patients predictably present 1–3 weeks after the onset of infection with symptoms extending into the recovery phase. Synovitis and clinical symptoms are often responsive to treatments used in other inflammatory arthropathies. This condition is typically monoar-
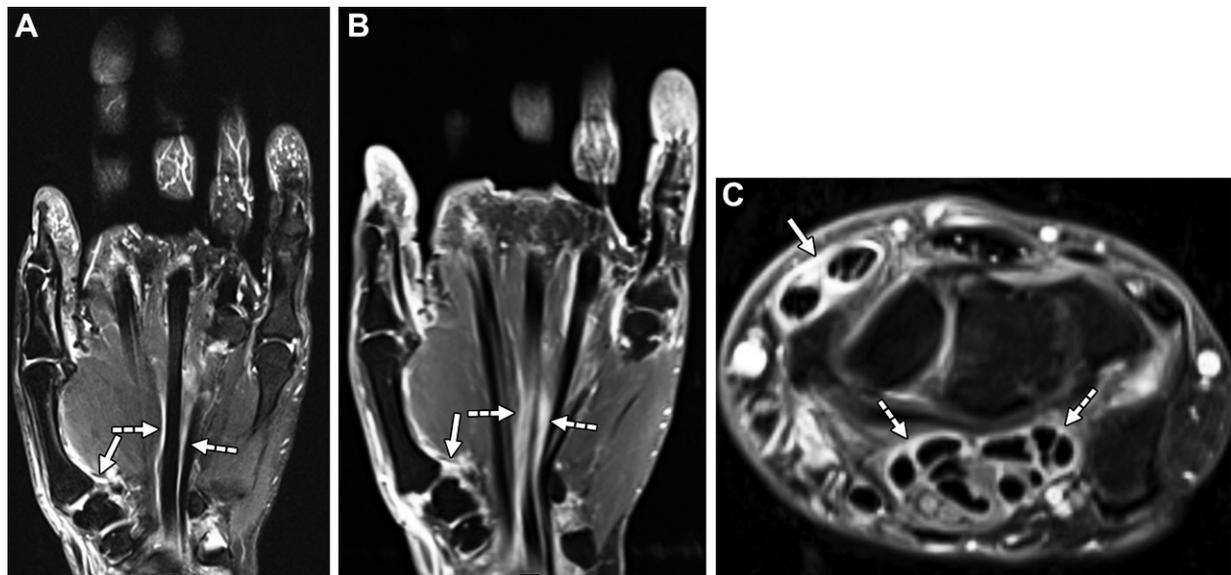
Figure 7.   Inflammatory arthritis in a 53-year-old woman who had recovered from COVID-19 2 weeks earlier and presented with intermittent arthralgias and swelling. **(A)** Coronal T2-weighted fat-suppressed MR image of the palm of the hand shows oligoarticular arthritis of the first carpometacarpal joint with periarticular soft-tissue edema (solid arrow in **A** and **B**), along with flexor bursal synovial edema (between dashed arrows in **A** and **B**). Note mild fifth metacarpophalangeal radial pericapsular edema without associated erosions or bone marrow edema. **(B)** Coronal T1-weighted fat-suppressed postcontrast MR image of the same area shows enhancement of the affected regions, indicating active inflammation and synovitis. **(C)** Axial T1-weighted fat-suppressed postcontrast MR image of the wrist through the proximal carpal row shows synovial enhancement in the second extensor compartment (solid arrow) and the flexor tendon bursae (dashed arrows), consistent with active synovitis.

ticular or oligoarticular and more commonly seen in the lower extremities and in men. The findings may be a manifestation of reactive arthritis, which is also usually monoarticular or oligoarticular (27). In comparison, inflammatory arthritis occurring with other viral infections usually manifests during the acute viremic phase of infection and is more commonly polyarticular (28).

Several possible mechanisms for the development of post–COVID-19 inflammatory arthritis have been proposed, the most common of which is molecular mimicry owing to viral epitopes on the spike protein causing production of autoantibodies. Other mechanisms, such as bystander activation, an antigen-independent stimulation of T cells and/or B cells in sites of inflammation, can also contribute to and exacerbate the autoimmune effects (29). Direct viral injury is considered unlikely as viremia is seen in only about 15% of COVID-19 patients and no detectable viral particles have been recovered in polymerase chain reaction (PCR) testing of arthrocentesis samples of a few patients (10,30).

Although most reported cases of COVID-19–related inflammatory arthropathy represent reactive postviral arthritis, other inflammatory arthropathies such as polyarticular RA, systemic lupus erythematosus, and seronegative spondyloarthropathies have been reported. Cases of seropositive RA have usually been described several weeks after the onset of moderate to severe pulmonary symptoms (10). Some patients pres-

ent with symptoms of active sacroiliitis, possibly associated with activation or exacerbation of seronegative spondyloarthropathies such as psoriatic arthritis, or post–COVID-19 reactive sacroiliitis. Clinical and imaging features established by the Assessment of SpondyloArthritis International Society (ASAS) can help confirm the diagnosis of seronegative spondyloarthropathy (31). It is unclear if there is an association of human leukocyte antigen B27 (HLA-B27) with seronegative spondyloarthropathies that follow COVID-19 (32).

The imaging findings of post–COVID-19 inflammatory arthritis are uncommonly reported but are similar to those of viral arthritis from other infections. MRI demonstrates monoarticular or oligoarticular synovial thickening and edema of the affected joints, and there may be tenosynovitis, with variable degrees of contrast enhancement (33) (Fig 7). Periarticular osseous erosions are rare. This could be related to early stages of disease or because medications used to treat other manifestations of COVID-19, such as corticosteroids or hydroxychloroquine, may blunt the severity of the synovitis (10). The presence of erosions may suggest an underlying rheumatologic disease such as RA (34). Similarly, US can help detect synovial thickening, which may be heterogeneous or hypoechoic relative to other tissues. There may be variable periarticular vascularity at Doppler US, ranging from no detectable hyperemia, indicating bland synovial proliferation, to extensive hyperemia, consistent

with active synovitis (33). Newer microvascular Doppler US techniques may be more sensitive in detecting active synovitis (35) (Fig 8).

MRI is the most sensitive imaging test for detecting sacroiliitis, including symmetric subchondral marrow edema and erosions, particularly in the lower and posterior thirds of the joint (Fig 9). Some patients may demonstrate synovial and capsular edema at fluid-sensitive imaging and synovial and capsular enhancement after intravenous contrast material administration (32). Although chronic changes of sacroiliitis described with other conditions, such as subchondral sclerosis, subchondral fat deposition, and ankylosis, have not been described, this may be because longitudinal assessment of patients with COVID-19–related sacroiliitis has not been performed.

Ascani et al (36) reported a case series of 12 patients who developed adhesive capsulitis following asymptomatic or mild COVID-19 with symptom occurrence 1.5–3 months following COVID-19 diagnosis. The authors speculated that there was a combination of direct effects from viral infection of fibroblasts and monocytes within the synovium, cytokine dysregulation inducing inflammation and subsequent fibrosis, and lifestyle changes, including decreased physical activity, which contribute to its development (36) (Fig 10).

Hematologic Manifestations

COVID-19 is a well-known cause of hypercoagulability. The cause is likely multifactorial and represents the interplay of inflammatory dysregulation, endothelial dysfunction, and venous stasis, often occurring in patients who are immobile and hospitalized. Thromboembolism may involve numerous organ systems. In addition to small vessel thrombosis, which is one of the hallmarks in autopsies of COVID-19 patients with respiratory and multisystem organ failure, large vessel venous thromboembolism is also common (9). Deep venous thrombosis (DVT) occurs in about 20%–25% of hospitalized patients and may result in pulmonary embolism (37). The reported cases of recurrent venous thromboembolism with COVID-19 provide additional evidence of its prothrombotic state.

Imaging is used to confirm the diagnosis, location, and extent of macrothrombosis. Most cases of COVID-19–related DVT have been described in the lower extremities, either in the calf musculature and popliteal vein or the femoral vein with central propagation. Classic findings of acute venous thrombosis are best diagnosed at gray-scale and color and spectral Doppler US (38).

Arterial thrombosis is described in 1%–2% of COVID-19 patients who are critically ill. Although a causal link is unclear, several centers have observed a significantly higher frequency of
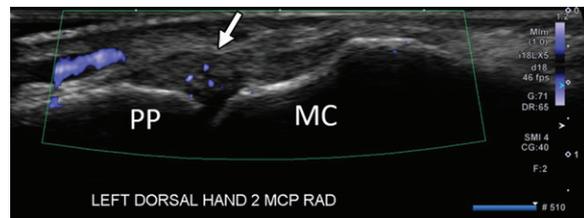

Figure 8. Inflammatory arthritis in a 43-year-old man who had recovered from mild COVID-19 a few weeks earlier and presented with scattered areas of bilateral hand arthralgia and periarticular swelling. The left second metacarpophalangeal *(MCP)* joint was among the affected joints. Long-axis microvascular Doppler US image of the radial margin of the second MCP joint shows a mildly thickened synovial fluid complex with mild hyperemia (arrow), indicating active synovitis. No articular erosions were seen, and no significant periarticular vascularity was seen at color Doppler US of the same region. *MC* = metacarpal (head), *PP* = proximal phalanx.

arterial thrombosis in COVID-19 patients without preexisting atherosclerotic disease or other causes of hypercoagulability, often with multivessel involvement. Critical illness, obesity, male sex, and history of coronary artery disease are the greatest risk factors for developing this complication (39).

CT angiography is the study of choice to help diagnose arterial thrombosis, with classic imaging findings well described in the literature (38). Simultaneous imaging of the contralateral extremity may help to detect subtle abnormalities (Fig 11). MRI may also help provide the diagnosis in patients unable to receive iodinated contrast material. Classic MRI findings include loss of the normal intravascular flow void, arterial distention, perivascular edema, and soft-tissue edema. MR angiography, with a lack of normal enhancement in the area of thrombosis, may contribute to the diagnosis (40).

COVID-19–related coagulopathy resulting in spontaneous MSK hemorrhage is much less common than thromboembolism. Spontaneous bleeding most commonly occurs in skeletal muscle, especially the iliopsoas, as well as the pectoralis major and rectus abdominis muscles (41,42). A recent study showed that critically ill COVID-19 patients were twice as likely to develop a spontaneous iliopsoas hematoma compared with those in the intensive care unit for other reasons (41). Patients may have acute progressive pain, swelling, development of a mass, and possibly skin bruising, with decreasing hemoglobin levels. Larger hematomas may cause mass effect on adjacent structures, such as peripheral nerves, and result in compressive neuropathy (43). Anticoagulation therapy is the biggest risk factor for developing spontaneous muscle hematoma. Other risk factors include older age, obesity, hypertension, and diabetes mellitus (42). Several proposed mechanisms may contribute to the pathogenesis of this phe-

Figure 9. Sacroiliitis in a 55-year-old man with a history of COVID-19 2 months earlier and subsequent low back and perianal pain. A full workup failed to show a gastrointestinal cause for the patient's symptoms. Given the patient's age (>45 years) and the lack of classic inflammatory back pain symptoms or history of psoriasis or inflammatory bowel disease, an axial spondyloarthritis was felt to be unlikely, and the HLA-B27 receptor status is unknown. **(A)** Coronal oblique T1-weighted non–fat-suppressed MR image of the sacroiliac joints shows bilateral sacroiliac erosions with irregularity of the subchondral bone plates (arrows) that are more pronounced on the iliac side of the joints. **(B, C)** Coronal oblique T2-weighted fat-suppressed **(B)** and coronal oblique T1-weighted fat-suppressed postcontrast **(C)** MR images of the same area show bone marrow edema and enhancement in the areas of erosion (arrows), suggestive of active lesions. The findings are slightly worse on the right, where they extend more cranially and involve the sacral side of the joint to a greater degree.
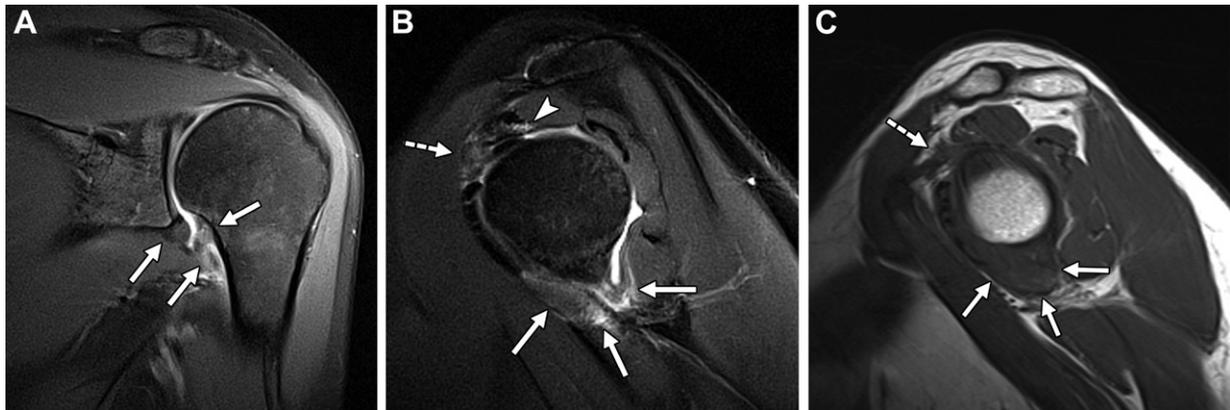

Figure 10. Adhesive capsulitis in a 46-year-old woman who developed atraumatic left shoulder pain and decreased range of motion 2 months after recovering from mild symptoms of COVID-19. **(A)** Coronal T2-weighted fat-suppressed MR image of the shoulder shows typical findings often seen with adhesive capsulitis, including an edematous thickened inferior glenohumeral ligament (IGHL), particularly at its humeral attachment (arrows). **(B)** Sagittal T2-weighted fat-suppressed MR image of the shoulder again shows edema of the IGHL (solid arrows), with additional mild rotator interval edema and thickening of the coracohumeral ligament (dashed arrow). Mild supraspinatus myotendinous junction edema is also seen (arrowhead). **(C)** Sagittal T1-weighted non–fat-suppressed MR image of the same area confirms thickening and ill definition of the coracohumeral ligament (dashed arrow). The fat within the rotator interval is still partially preserved. The IGHL also appears thickened diffusely (solid arrows). The MRI findings are compatible with the freezing or inflamed phase of adhesive capsulitis.

nomenon, including prophylactic anticoagulation therapy and renal damage–associated decreased clearance of anticoagulants. Additionally, SARS-CoV-2 infection and the subsequent cytokine storm may result in endothelial inflammation and damage leading to capillary microtrauma and arterial vulnerability (42).

If the clinical diagnosis is unclear, CT is an excellent initial modality since it can be performed rapidly over large fields of view. Noncontrast imaging will show muscle enlargement with a hyperattenuating collection if the patient is not anemic, possibly with a fluid-hematocrit level. Intravenous contrast material is usually unnecessary. MRI may be performed in patients in whom alternate diag-

noses are suspected and can be helpful to assess for compression on surrounding structures. The signal intensities of MSK hematomas are usually heterogeneous depending on the composition of blood products, without internal enhancement in the absence of an underlying mass (41). Compression of motor nerves may result in denervation muscle edema at fluid-sensitive imaging and possibly atrophy at non–fat-suppressed T1-weighted imaging in cases of longer-standing compression (Fig 12). US examination often shows a complex heterogeneous lesion, sometimes with dependent fluid and/or hematocrit levels and septa and without nodular or internal vascularity to indicate an underlying solid mass (44).
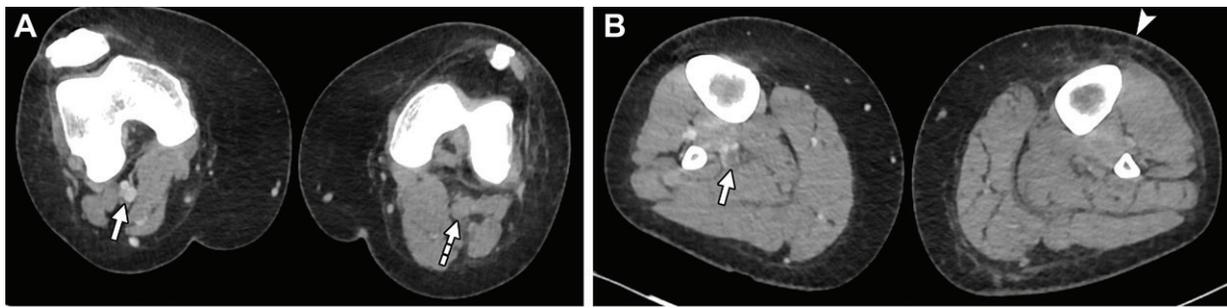
Figure 11.   Arterial and venous lower extremity thrombosis in a 49-year-old man with a history of COVID-19 who presented with left lower extremity pain, swelling, and pulselessness. **(A)** Axial CT angiographic image of the lower extremities at the level of the femoral condyles shows contrast material opacifying the right popliteal artery and vein (solid arrow) but not the left (dashed arrow), consistent with thrombosis. **(B)** More distal axial CT angiographic image of the calves shows near-complete nonopacification of the right popliteal vein with a thin rim of surrounding contrast material (solid arrow), indicating near-occlusive thrombosis. In the left lower leg, there is subcutaneous stranding (arrowhead), consistent with soft-tissue edema. The multifocal arterial and venous thrombi are suggestive of a hypercoagulable state. **(C)** Three-dimensional reformatted coronal CT angiographic image shows absence of opacification of the left popliteal artery and its major branches (dashed arrow) owing to the arterial thrombosis. In comparison, the right popliteal artery and its major branches are well opacified (solid arrow), consistent with patency.

Secondary Infections

Secondary infections, such as bacteremia and urinary or respiratory tract infections, are common and may be seen in up to 50% of hospitalized COVID-19 patients (45). Otherwise, spontaneous MSK infections, such as intramuscular abscesses and septic arthritis, are uncommon in immunocompetent patients. One orthopedic study showed an unusually high frequency of periprosthetic infections, soft-tissue abscesses, and septic arthritis over 1 year in 12 of 90 hospitalized COVID-19 patients (46). Talamonti et al (47) described six hospitalized COVID-19 patients with spinal epidural abscesses within a 3-month span, most without risk factors for developing MSK infections. Risk factors such as diabetes mellitus may contribute to increased infection rate. *Staphylococcus aureus* is the most common causative organism, although unusual organisms like *Fusobacterium* and *Actinomyces* species have also been described.

While the causes of these infections are unknown, COVID-19 patients frequently develop lymphopenia, which could lead to a consumptive immunocompromise. Alternatively, vascular endothelial damage may allow virulent organisms to more easily penetrate vessels walls and seed surrounding tissues. Direct viral damage seems unlikely since a few case reports in which abscess fluid was recovered failed to show viral particles at PCR testing (48). Imaging of soft-tissue abscesses, including with US, CT, and MRI, is well described in the literature. MRI is the best modality to assess axial and appendicular MSK infections including spinal epidural abscesses (Fig 13). Intravenous contrast material is helpful for detecting rim-enhancing abscesses and may be substituted with diffusion-weighted sequences as needed (49,50).

Peripheral Nerve Manifestations

COVID-19–associated peripheral neuropathies are more commonly described in patients who are critically ill and require ventilation and have several possible causes, including GBS, toxic neuropathy, critical illness polyneuropathy (CIP), compressive neuropathy, and position-related neuropathy (51). While damage from direct viral infection was initially considered a possible mechanism, more recent evidence suggests other causes are likely, since viral particles are rarely recovered in PCR testing of the nerves and cerebrospinal fluid in most patients
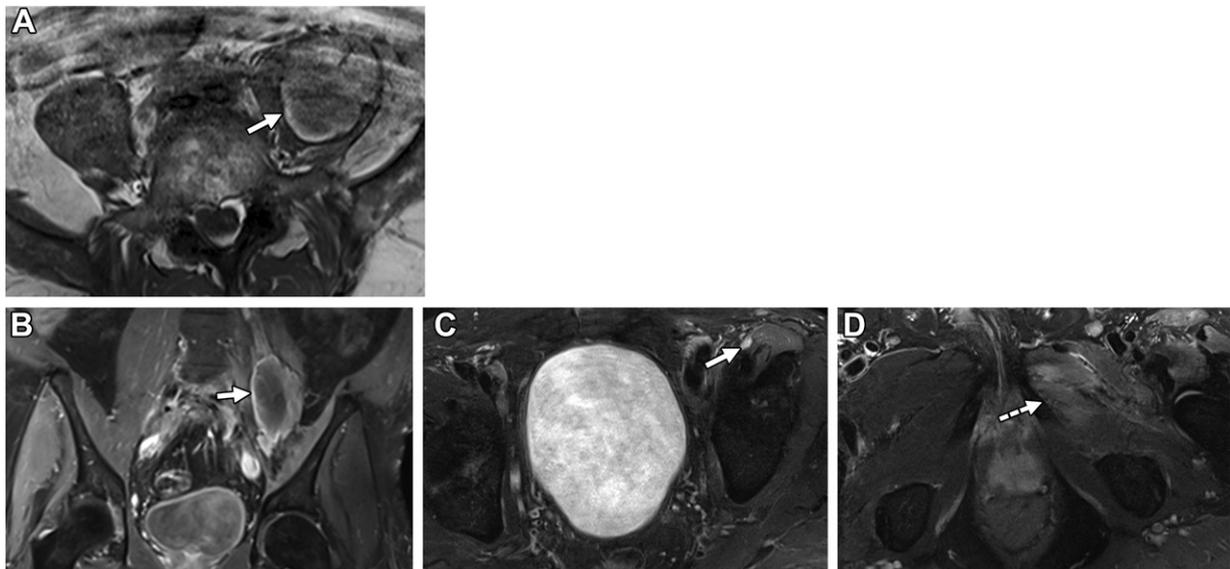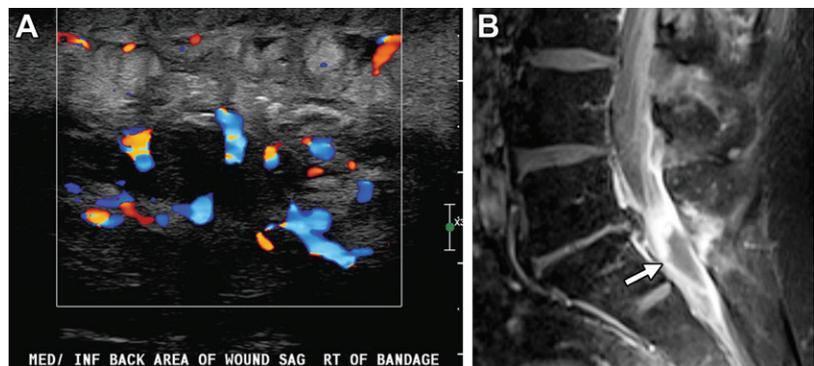
Figure 12. Spontaneous intramuscular hematoma resulting in acute muscle denervation from compressive neuropathy in a 60-year-old man with COVID-19 undergoing anticoagulation therapy who presented with left flank pain radiating to the left inguinal region. **(A)** Axial T1-weighted non–fat-suppressed MR image of the retroperitoneum shows a heterogeneous left iliopsoas collection (arrow) with a thin peripheral dark rim related to a pseudocapsule and hemosiderin deposition, an inner ring of high signal intensity and a central core of lower signal intensity, related to blood products in various stages (concentric ring sign). **(B)** Coronal T1-weighted fat-suppressed postcontrast MR image of the pelvis shows the inner ring of hyperintense signal (arrow) without significant enhancement of the collection. **(C)** Axial T2-weighted fat-suppressed MR image of the pelvis inferior to **A** shows edema of the left femoral nerve (arrow), consistent with compressive neuropathy. **(D)** More inferior axial T2-weighted fat-suppressed MR image of the inguinal regions shows anterior and anteromedial muscle edema (arrow), most pronounced in the adductor compartment, consistent with compressive femoral neuropathy.

Figure 13. Secondary infections in two patients. **(A)** Transverse color Doppler US image of the lower back in a 34-year-old woman with type I diabetes mellitus and subsequent COVID-19 who presented with worsening back pain, swelling, and fevers shows typical findings of a subcutaneous abscess, including an anechoic collection with marked surrounding hyperemia. The subcutaneous fat in the near-field is echogenic and has irregular hypoechoic septa (cobblestone appearance), representing edema and probably phlegmon. The results of a fine-needle aspiration confirmed methicillin-susceptible *S aureus*. **(B)** Sagittal T1-weighted fat-suppressed midline postcontrast MR image of the lower lumbar spine in a 66-year-old man hospitalized for COVID-19 respiratory infection who developed back pain radiating to the lower extremities and fevers shows a peripherally enhancing collection within the spinal canal (arrow), consistent with an epidural abscess. The patient was diagnosed with methicillin-resistant *S aureus* bacteremia.

(52). Risk factors include male sex, age greater than 50 years, diabetes mellitus, hypertension, and prolonged intensive care unit stay (53).

In a mini-review by Finsterer et al (53), the most commonly reported COVID-19–related peripheral neuropathy was GBS (53). Whether GBS is truly a consequence of COVID-19 has been debated, although several centers have reported a significant increase in GBS cases during the COVID-19 pandemic in patients without other recognized causes (54). Although GBS in COVID-19 can be parainfectious, most reported cases are postinfectious, starting about 5–10 days after the onset of COVID-19 symptoms (55).

MRI is the best imaging modality to help assess GBS and is usually performed to exclude other possible causes, such as central nervous system insults. Lumbar spine MRI may show distal spinal cord hyperintensity at T2-weighted imaging and nerve root thickening of the cauda equina, with surface enhancement of these nerve roots as well as the conus medullaris (51) (Fig 14). Occasionally, there can be leptomeningeal and spinal nerve root enhancement on brain MR images (56).

CIP occurs in critically ill patients and results in a symmetric lower limb–predominant flaccid muscle weakness that can involve the phrenic nerve and muscles of respiration, similar to GBS.
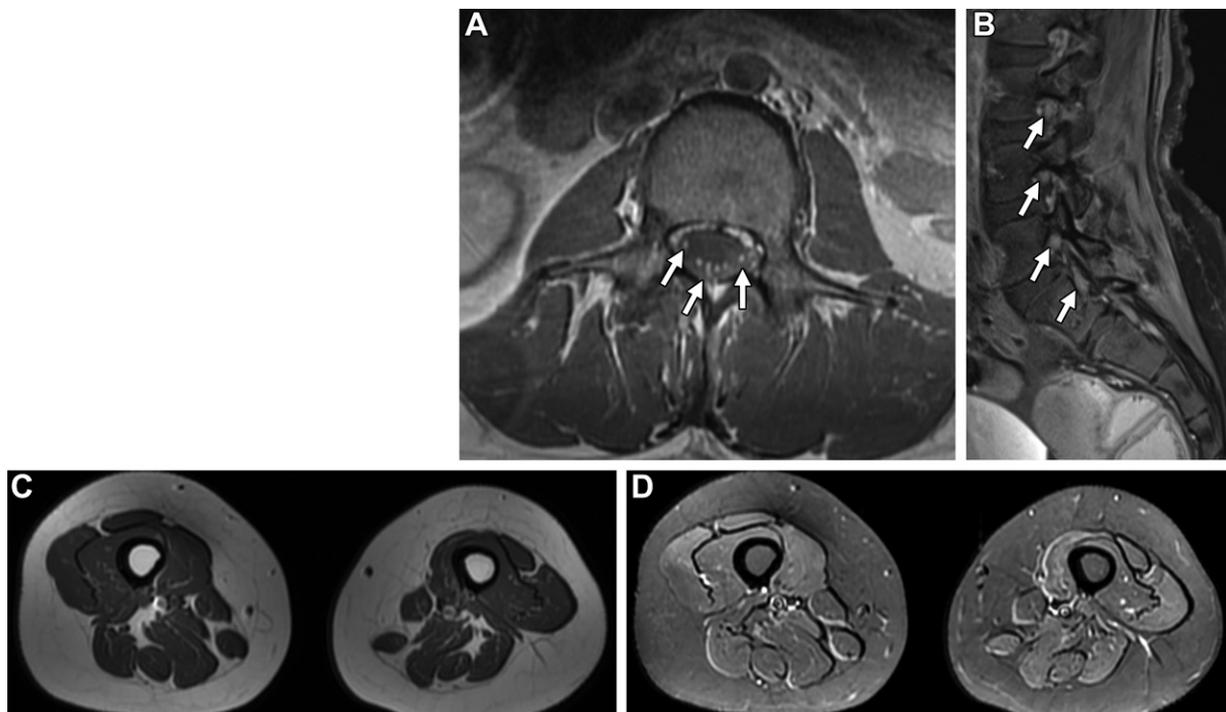
Figure 14. GBS in a 15-year-old adolescent girl with COVID-19 with progressive ascending lower extremity pain and weakness. The patient was diagnosed with COVID-19–related acute motor axonal neuropathy (AMAN), a variant of GBS, and myopathy due to either AMAN, critical illness myopathy, or both. **(A, B)** Axial T1-weighted non–fat-suppressed postcontrast MR image of the lumbar spine at the L3 level **(A)** and sagittal T1-weighted fat-suppressed postcontrast MR image of the lumbar spine through the left neural foramina **(B)** show thickening and enhancement of the nerve roots (arrows). **(C)** Axial T1-weighted non–fat-suppressed MR image of the mid thighs shows diffuse left thigh muscle atrophy, particularly in the posterior compartment, with more subtle right thigh posterior compartment decreased muscle bulk. **(D)** Axial short τ inversion-recovery (STIR) MR image at the same level shows mild diffuse left thigh muscle edema and subtle left thigh anterior compartment muscle edema, which may indicate areas of greater disease activity.

Unlike GBS, it rarely involves the facial muscles. Several factors can contribute to its pathogenesis. Imaging is nonspecific and usually performed to exclude other causes. MRI can show muscle edema and possibly fatty infiltration, worse in the lower extremities, and can help to direct muscle biopsy when indicated (5).

Other categories of peripheral neuropathy with described imaging findings in COVID-19 patients include position-related, compressive, and postinfectious neuropathies that may be related to thrombotic microangiopathy (Fig 15). Prolonged prone positioning can cause excessive traction and ischemia of peripheral nerves. Unlike GBS and CIP, this is more frequent in younger patients, commonly involves the upper extremities, particularly the ulnar nerve and cords of the brachial plexus, and may be unilateral or asymmetric. Lower extremity neuropathies most often involve the sciatic and common peroneal nerves (57). There may be localized nerve damage from microvascular injury, cytokine-mediated inflammation, and possibly compression within fibro-osseous tunnels such as the carpal and cubital tunnels (58).

Both high-spatial-resolution MR neurography and US are useful in characterizing peripheral neuropathies. Intravenous contrast material is usually unnecessary since peripheral nerves in these conditions do not generally enhance. However, contrast material can help suppress vascular signal intensity, especially during isotropic three-dimensional short τ inversion-recovery (STIR) techniques, making the distinction between peripheral nerves and blood vessels clearer. There may also be associated muscle edema with fluid-sensitive sequences, and/or decreased muscle bulk and muscle fatty atrophy on T1-weighted non–fat-suppressed images corresponding to a peripheral nerve distribution (51) (Fig 16).

US is an excellent modality for assessing peripheral nerves. Similar to MRI, the nerves may appear thickened in areas of neuropathy, and one or more fascicles may be enlarged and hypoechoic. Alternatively, there may be effacement of the normal fascicles, producing a swollen featureless appearance (59). Newer microvascular Doppler US techniques may detect slow-flow intraneural vascularity indicating focal nerve abnormality (60).

Several medications specifically used in treating COVID-19, such as hydroxychloroquine and remdesivir, can result in toxic neuropathies, which are usually diagnosed clinically and aided by electrodiagnostic examinations rather than imaging examinations (51).
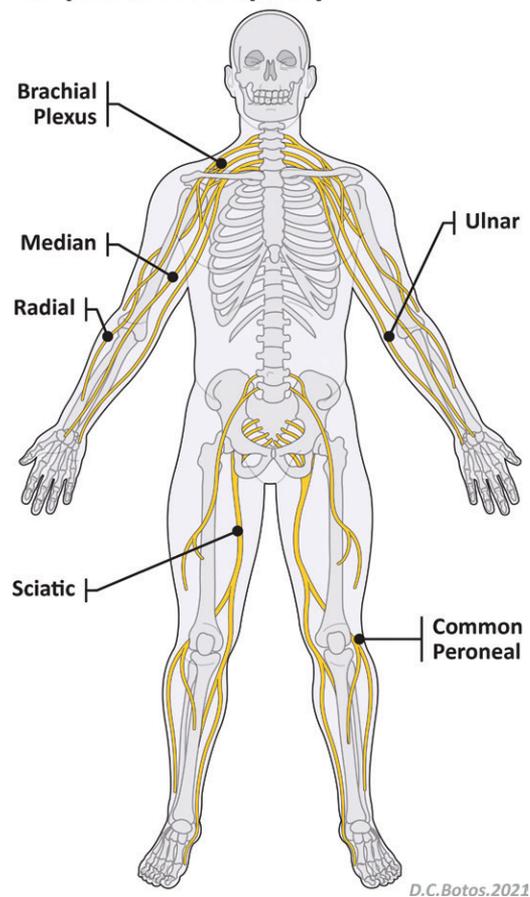
Peripheral Neuropathy

Figure 15. Diagram shows the most frequently reported sites of peripheral neuropathy in patients with COVID-19. The upper extremity, particularly the ulnar nerve and brachial plexus, is more commonly affected than the lower extremity.

Post–COVID-19 Condition

Post–COVID-19 condition may be seen in 10%–20% of patients, generally in younger individuals between 20 and 50 years of age. In October 2021, the World Health Organization released the following consensus definition: "Post COVID-19 condition occurs in individuals with a history of probable or confirmed SARS CoV-2 infection, usually 3 months from the onset of COVID-19 with symptoms and that last for at least 2 months and cannot be explained by an alternative diagnosis…. Symptoms may be new onset following initial recovery from an acute COVID-19 episode or persist from the initial illness (61)." Several of these symptoms, such as fatigue, shortness of breath, arthralgias, muscle pain and/or spasms, and postexertional malaise, can be related to the chronic impact of COVID-19 on skeletal muscle.

Long-standing COVID-19–related myopathy can result in muscle weakness, spasms, and exercise intolerance and is associated with decreased muscle bulk and fatty infiltration. These may be associated with denervation atrophy, decondition-

ing and sarcopenia, immune-mediated myopathy, toxic myopathy, and nutritional deficiencies (62). The findings may be unilateral or asymmetric depending on the involved nerves (63).

MRI, CT, or US can be performed to detect well-described chronic muscle changes (Fig 17). If there is enough fatty infiltration, the overall muscle cross-sectional area may not be significantly reduced. In these cases, fat quantification techniques, such as with Dixon MRI, can provide a measure of muscle atrophy that can aid serial assessment. Intravenous contrast material is generally unnecessary, since denervated atrophic muscle usually does not enhance (64).

Although US is helpful in detecting focal or patchy muscle atrophy compared with normal-appearing adjacent muscle, it may be more difficult to detect global balanced muscle abnormalities (64). Shear wave sonoelastography can be useful to quantitatively assess muscle stiffness and is an emerging technique that can help detect early abnormalities and follow progression of atrophy (65).

Sarcopenia, which is generally seen with aging and deconditioning, can be more pronounced in COVID-19 patients who are critically ill and may affect the muscles of respiration, inhibiting the ability to wean patients from ventilators. Although this is likely indirectly due to COVID-19 through prolonged immobilization, diffuse COVID-19–related myopathy may also contribute to its development. CT and MRI are commonly performed to detect and follow findings of sarcopenia. Assessment of skeletal muscle cross-sectional area, normalized with respect to patient sex, age, and occasionally body mass index, is commonly performed at the L3 vertebral level, which is the imaging reference standard (66) (Fig 18). Recent work has validated that cross-sectional area measurements between T10 and T12 or at the T4 level can be useful surrogates in chest CT examinations performed in many patients with COVID-19 (66).

Respiratory muscle dysfunction can involve the diaphragm. Long-standing diaphragmatic dysfunction is seen in up to 76% of COVID-19 patients and can contribute to dyspnea in the post–COVID-19 condition. Several factors likely contribute to its pathogenesis, including sarcopenia, critical illness myopathy, and ventilator-induced dysfunction. Diaphragmatic dysfunction historically has been assessed fluoroscopically by using the sniff test but can be assessed over successive breaths at M-mode US (Fig 19). With quiet breathing, the normal excursion has been reported as 10 mm for men and 9 mm for women. In cases that are equivocal during quiet breathing, assessing excursion during deep breathing (with deep inspiration and terminal expiration) may be useful. Normal values for excursion with deep breathing are 47
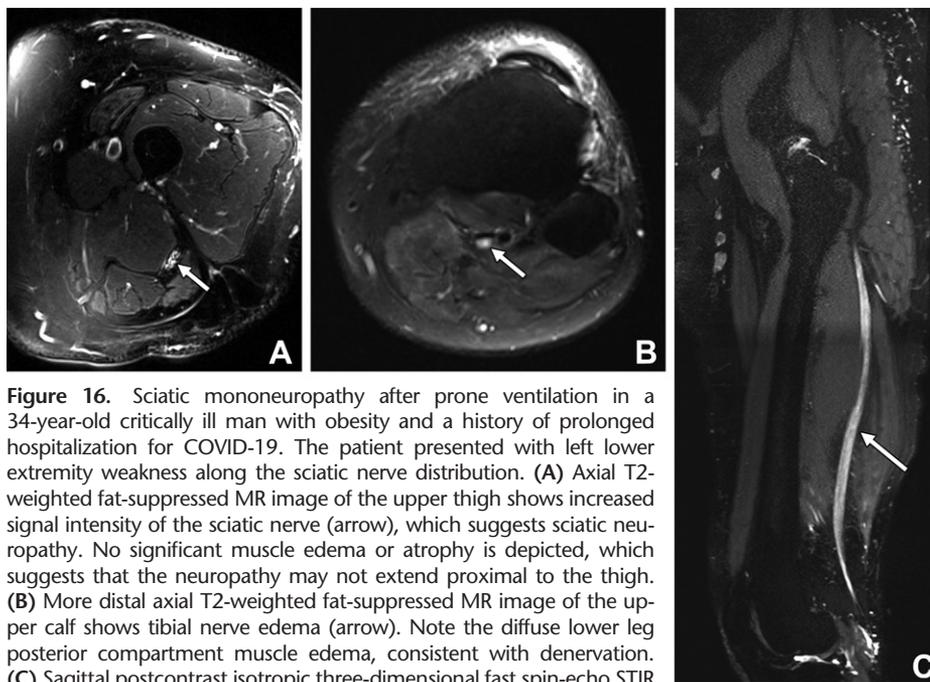
Figure 16. Sciatic mononeuropathy after prone ventilation in a 34-year-old critically ill man with obesity and a history of prolonged hospitalization for COVID-19. The patient presented with left lower extremity weakness along the sciatic nerve distribution. **(A)** Axial T2-weighted fat-suppressed MR image of the upper thigh shows increased signal intensity of the sciatic nerve (arrow), which suggests sciatic neuropathy. No significant muscle edema or atrophy is depicted, which suggests that the neuropathy may not extend proximal to the thigh. **(B)** More distal axial T2-weighted fat-suppressed MR image of the upper calf shows tibial nerve edema (arrow). Note the diffuse lower leg posterior compartment muscle edema, consistent with denervation. **(C)** Sagittal postcontrast isotropic three-dimensional fast spin-echo STIR reformatted MR image shows the long-axis extent of the sciatic neuropathy from the femoral subtrochanteric level through the popliteal fossa (arrow). No space-occupying lesions are depicted along the course of the sciatic nerve.

Figure 17. Asymmetric muscle denervation atrophy in a 37-year-old woman with a history of mechanical ventilation owing to COVID-19. The patient experienced subsequent sciatic mononeuropathy with long-standing hamstring and lower leg weakness. **(A)** Axial T2-weighted fat-suppressed MR image of the left mid thigh shows left sciatic nerve edema (solid arrow). There is posterior compartment diffuse muscle edema, particularly involving the semimembranosus muscle (dashed arrow). **(B)** Axial T1-weighted non–fat-suppressed MR image at the same level shows posterior compartment–predominant muscle atrophy and fatty infiltration, also more pronounced in the semimembranosus muscle (arrow). The findings are consistent with denervation in the sciatic nerve distribution that has a chronic component given the muscular atrophy.
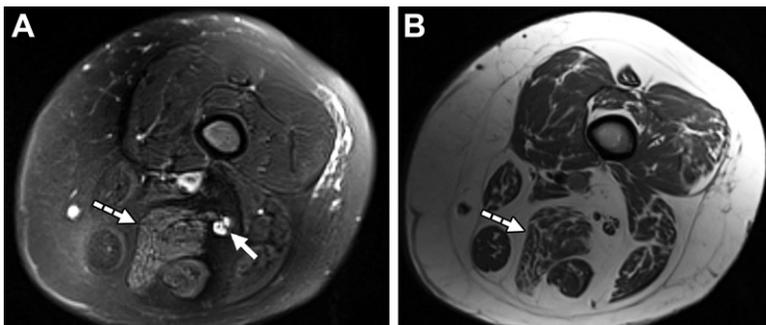
mm for men and 37 mm for women (67,68). The value of diaphragmatic US in patients who require ventilators is still being assessed and may also depend on the mode of ventilation.

Vaccine-related Manifestations

Since December 2020, COVID-19 vaccinations have been used to decrease the severity of disease and the likelihood of disease transmission. To date, more than 11.6 billion doses of various COVID-19 vaccines in 5.1 billion people have been administered worldwide, which represents 67% of the world's population (1). While COVID-19 vaccination is considered very safe and effective, several reactions similar to those of other vaccines have been reported, including localized pain and swelling at the injection site and possibly myalgias and arthralgias for a few days following the injection. Rarely, MSK

symptoms can persist for months and may even become chronic.

Most adult vaccines are administered intramuscularly into the lateral or posterolateral deltoid muscle, about 3 cm inferior to the lateral margin of the acromion. Postvaccination shoulder pain lasting more than a few days and not well controlled by common conservative measures occurs in up to 2% of injections (69). The most common postvaccination condition is shoulder injury related to vaccine administration (SIRVA), which was first described in 2006 (70). Classically, patients develop rapid onset of shoulder pain and decreased range of motion within 48 hours of vaccination. This is most often following the influenza vaccination, probably owing to the frequency that this vaccine is administered. SIRVA is likely related to a localized immunologic reaction to the injectate, and several authors have suggested that
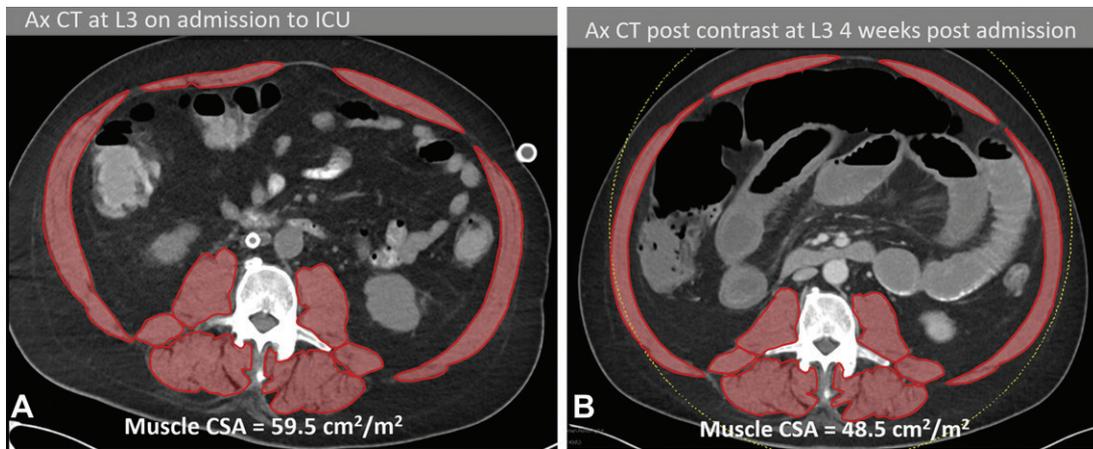
Figure 18. Sarcopenia in a 54-year-old man hospitalized for COVID-19 acute respiratory distress syndrome who was diagnosed with weakness and global pelvic muscle atrophy. **(A)** Axial CT image of the abdomen at the L3 level was obtained at patient admission, and subsequent skeletal muscle cross-sectional area quantification measured 59.5 cm²/m². **(B)** Repeat axial CT image of the abdomen at the L3 level 4 weeks later, after an extended stay in the intensive care unit, shows that the skeletal muscle cross-sectional area has decreased to 48.5 cm²/m², indicating sarcopenia.
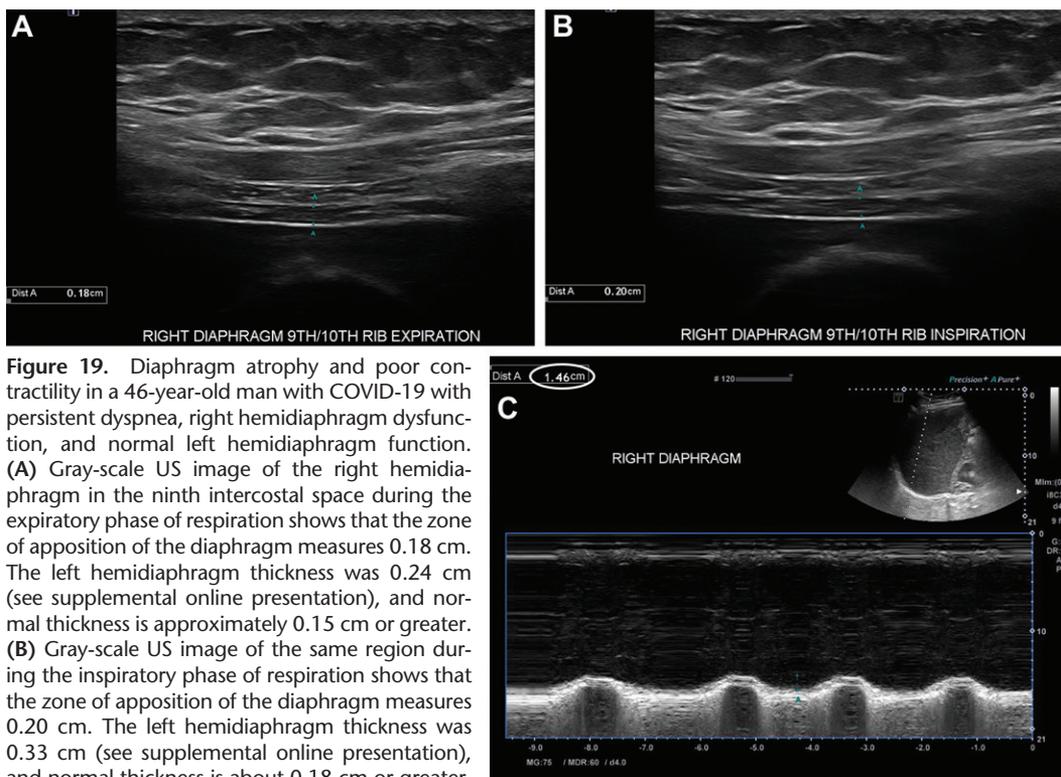

Figure 19. Diaphragm atrophy and poor contractility in a 46-year-old man with COVID-19 with persistent dyspnea, right hemidiaphragm dysfunction, and normal left hemidiaphragm function. **(A)** Gray-scale US image of the right hemidiaphragm in the ninth intercostal space during the expiratory phase of respiration shows that the zone of apposition of the diaphragm measures 0.18 cm. The left hemidiaphragm thickness was 0.24 cm (see supplemental online presentation), and normal thickness is approximately 0.15 cm or greater. **(B)** Gray-scale US image of the same region during the inspiratory phase of respiration shows that the zone of apposition of the diaphragm measures 0.20 cm. The left hemidiaphragm thickness was 0.33 cm (see supplemental online presentation), and normal thickness is about 0.18 cm or greater. The contractility ratio, which is the thickness of the zone apposition with inspiration divided by the thickness during expiration, measures 1.1, and normal is at least 1.2. **(C)** M-mode US image of the diaphragm over several deep breaths shows that the diaphragmatic excursion, which is the height of the diaphragm with terminal expiration minus the height of the diaphragm during deep inspiration, measures 1.46 cm. Although the absolute thickness of the diaphragmatic zone of apposition on the right is normal with inspiration and expiration, there is a significant difference between the right and left sides, and the contractility ratio is lower than expected. Furthermore, the diaphragmatic excursion with deep breathing is much less than expected. Together, these findings are consistent with left hemidiaphragm atrophy and dysfunction.

this is more common when there has been a prior exposure that sensitizes a patient. SIRVA usually occurs with improper positioning of the needle tip, particularly within the upper third of the deltoid, possibly extending into the subacromial-subdel-toid bursa, rotator cuff tendons, glenohumeral joint, or even the humerus, which may result in bursitis, rotator cuff tendinopathy, glenohumeral joint synovitis, adhesive capsulitis, and osteitis and/or osteomyelitis (71) (Fig 20).
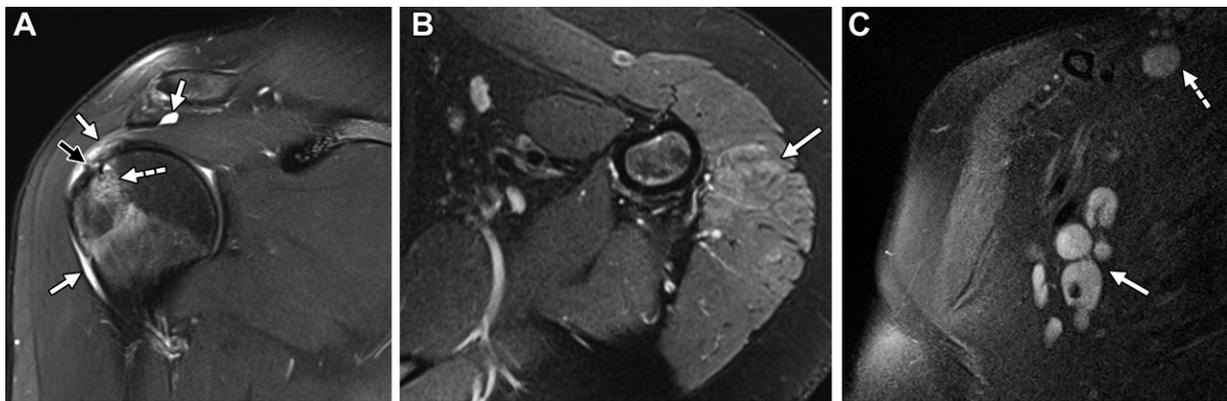
Figure 20.   COVID-19 vaccine–related findings in three patients. **(A)** Coronal T2-weighted fat-suppressed MR image of the right shoulder in a 34-year-old woman with persistent pain and limited range of motion 2 months after receiving the Pfizer-BioNTech mRNA COVID-19 vaccine. The patient experienced progressive pain 3 days after her first dose of the vaccine and had no other trauma or prior shoulder injury. There is moderate subacromial-subdeltoid bursitis (solid white arrows), with tendinopathy at the junction of the supraspinatus and infraspinatus tendons and fraying (black arrow), and underlying superolateral humeral head marrow edema and irregularity (dashed arrow). The tendon and bone findings could be related to deep needle placement through the bursa and into the substance of the tendon. **(B)** Axial T2-weighted fat-suppressed MR image of the left shoulder in a 27-year-old woman who received the second dose of the Moderna mRNA COVID-19 vaccine 5 weeks earlier with continued shoulder pain and tenderness shows persistent mild ill-defined lateral deltoid muscle edema (arrow) at the site of maximal tenderness, thought to represent postinjection myopathy. No other findings to explain the patient's symptoms were seen. **(C)** Coronal T2-weighted fat-suppressed MR image of the anterior shoulder in a 45-year-old woman who received the first dose of the Pfizer-BioNTech COVID-19 vaccination 4 days earlier with new onset of shoulder pain and decreased range of motion shows reactive axillary lymphadenopathy (solid arrow). Note the additional enlarged supraclavicular lymph node (dashed arrow).

Patients with SIRVA related to COVID-19 vaccination seem to differ slightly from those following other vaccinations. First, several patients have developed symptoms 1–2 weeks after injection, and one patient reportedly developed symptoms 8 weeks after the injection (72). In these cases, the presenting symptoms were typical of SIRVA and no other inciting cause was found. Secondly, several reported cases developed after only one dose of the vaccine. These cases suggest that the inflammatory reaction may take some time to develop if there has not been prior exposure. In particular, the Pfizer-BioNTech and Moderna mRNA vaccines appear highly immunogenic and may produce a strong reaction when injected into nontarget synovial tissues (72).

Other injuries may occur if the needle placement is outside of the safe zone within the deltoid muscle. If the needle is too lateral, it may result in axillary nerve injury; if it is too inferior, it can injure the radial neurovascular bundle; if it is too long it could result in chemical osteitis/osteomyelitis of the humerus; and if it is too short, it can result in local skin reaction and subcutaneous fat necrosis (73).

Clustered enlarged axillary lymph nodes, commonly seen following COVID-19 vaccination, are likely reactive and may last for several months (74). Localized muscle edema with overlying mild subcutaneous and fascial edema may be present for a few days or weeks following injection. However, persistent muscle edema with localized shoulder pain may reflect focal myositis (75).

Rotator cuff tendon tears reported in some patients may be preexisting, but the inflammatory response may contribute to symptom development. Periarticular and articular infections are rare, with a single case of glenohumeral septic arthritis and subacromial-subdeltoid bursitis reported (49,76). As with other causes, potential COVID-19 vaccine–related rotator cuff, bursal, and other periarticular soft-tissue pathologic conditions may be diagnosed with MRI or US, while MRI remains the primary modality for glenohumeral joint evaluation (77).

There is literature reporting rare inflammatory MSK manifestations following COVID-19 vaccination, including reactive inflammatory arthropathies as well as flares of existing rheumatologic conditions and GBS, suggesting an autoimmune response. In a series of 66 patients reported by Ursini et al (78), the most common rheumatologic condition was a transient symmetric polymyalgia rheumatica-like inflammation (78). Uncommon mild flares of existing rheumatologic conditions such as RA or psoriatic arthritis have been described (79). Imaging studies of postvaccine immune-mediated MSK manifestations have not been well reported.

A meta-analysis showed that GBS following COVID-19 vaccine administration tended to manifest 1–3 weeks after administration of the first dose of the vaccine, more commonly in men and those over 50 years of age. Additionally, patients most commonly suffered from demyelinating polyneuropathy and bifacial weakness,

which may be defining characteristics of post–COVID-19 vaccine-related GBS (80).

Conclusion

COVID-19, a clinical syndrome produced by SARS-CoV-2 infection, has wide-reaching effects throughout the body, including the MSK system. The impact of these MSK manifestations on long-term patient outcomes has yet to be determined. Rare COVID-19 vaccine–related complications have also been reported. It is important for radiologists to understand the common patterns of COVID-19 involvement in the MSK system, including relevant imaging findings seen with various modalities, as imaging can help identify several MSK manifestations of COVID-19, assess the distribution of disease, and provide quantifiable measurements to follow disease progression.

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