Over the 12 months since the start of the coronavirus disease 2019 pandemic, an explosion of investigation and an increase in experience have led to vast improvement in our knowledge about this disease. However, coronavirus disease 2019 remains a huge public health threat. (J Am Soc Echocardiogr 2021; 34:707-714.)

**Keywords:** COVID-19, Pediatric, Fetal, Congenital, Heart disease

Over the 12 months since the start of the coronavirus disease 2019 (COVID-19) pandemic, an explosion of investigation and an increase in experience have led to vast improvement in our knowledge about this disease.

However, COVID-19 remains a huge public health threat. With ongoing fluctuations of disease prevalence and spread, countries, states, and municipalities have moved from strict lockdowns to varying degrees of restricted movement and activity. Further change is expected in the months ahead as pandemic surges continue amid the initiation of successful vaccine distribution. This evolution in the pandemic and community response requires us constantly to adapt our strategies for practice management.

During the initial phase of the pandemic, the American Society of Echocardiography (ASE) provided guidance to our echocardiography community with “Specific Considerations for Pediatric, Fetal, and Congenital Heart Disease Patients and Echocardiography Service Providers during the 2019 Novel Coronavirus Outbreak” as a supplement to the broader ASE statement. Initial concerns that elective office visits and procedures could fuel propagation among patients, families, and providers (particularly to pregnant women and fetuses and from asymptomatic children) along with incomplete knowledge of the best methods of mitigating transmission risk led to a dramatic reduction in echocardiographic services provided to pregnant women and pediatric and congenital heart disease patients.

As the pandemic trajectory somewhat ameliorated, the ASE released the statement “Reintroduction of Echocardiography Services during the COVID-19 Pandemic” in May 2020 to help echocardiography providers realign practice and care. In the months following these statements, we have learned much. We have observed that, typically, healthy children are less severely affected than adults...
risk in children with congenital heart disease because of underlying physiologic and anatomic abnormalities, yet these cases have been only rarely reported. Although children seem less predisposed to serious illness during the acute infection, a subset develop multi-system inflammatory syndrome in children (MIS-C), with potential accompanying hemodynamic compromise and myocardial dysfunction that may be severe enough to require support with extracorporeal membrane oxygenation in some cases. Chronic medical conditions posing additional risks in children overlap some risk factors in adults (obesity and diabetes) but diverge in others (less risk for asthma but higher risk for neurologic, genetic, and metabolic maladies, among others). There has been obvious concern for increased risk in children with congenital heart disease presenting postnatally that could have been detected and/or minority children are more likely infected, and there is increased risk for severe disease and complications in the very young or in those with chronic medical conditions. Chronic medical conditions during acute severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infection. Mortality of pediatric patients requiring hospitalization is low, at approximately 0.18%. Socioeconomically disadvantaged and/or minority children are more likely infected, and there is increased risk for severe disease and complications in the very young or in those with chronic medical conditions. There has been obvious concern for increased risk in children with congenital heart disease because of underlying physiologic and anatomic abnormalities, yet these cases have been only rarely reported. Although children seem less predisposed to serious illness during the acute infection, a subset develop multi-system inflammatory syndrome in children (MIS-C), with potential accompanying hemodynamic compromise and myocardial dysfunction that may be severe enough to require support with extracorporeal membrane oxygenation in some cases. Chronic medical conditions posing additional risks in children overlap some risk factors in adults (obesity and diabetes) but diverge in others (less risk for asthma but higher risk for neurologic, genetic, and metabolic maladies, among others). There has been obvious concern for increased risk in children with congenital heart disease presenting postnatally that could have been detected and/or minority children are more likely infected, and there is increased risk for severe disease and complications in the very young or in those with chronic medical conditions. Chronic medical conditions during acute severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infection. Mortality of pediatric patients requiring hospitalization is low, at approximately 0.18%. Socioeconomically disadvantaged and/or minority children are more likely infected, and there is increased risk for severe disease and complications in the very young or in those with chronic medical conditions. There has been obvious concern for increased risk in children with congenital heart disease presenting postnatally that could have been detected and/or minority children are more likely infected, and there is increased risk for severe disease and complications in the very young or in those with chronic medical conditions. Chronic medical conditions during acute severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infection. Mortality of pediatric patients requiring hospitalization is low, at approximately 0.18%.

The COVID-19 pandemic has required sonographers rapidly to change their work flow, personal safety measures, and examination protocols. The initial lockdowns decreased clinical volume so significantly that many sonographers had their hours flexed down and were at risk for being furloughed, raising personal financial stresses. Subsequently, as laboratories and clinics expand services, the drive to “catch up” on the accumulation of deferred examinations places different physical and emotional stresses on sonographers and laboratory personnel. The increase in number of patients coming to the echocardiography laboratory is occurring concurrently with resumption of complete, comprehensive echocardiographic examinations with longer scan times. Young children remain less compliant with facemasks and have difficulty cooperating, particularly during the long examinations necessary to evaluate complex congenital heart disease. Optimal social distancing is difficult or impossible to achieve in a small echocardiography examination room with a child, caretaker, and sonographer. Some sonographers considered at high risk for COVID-19 have chosen to stay home, leaving fewer on-site sonographers to tackle an increased workload. Sonographer availability is also limited by the quarantine required when suspicious symptoms arise or a COVID-19 exposure occurs. All of these factors can lead to sonographer exhaustion and burnout, similar to what is observed in other frontline providers. To minimize this fatigue, measures to ensure

### Table 1 CDC gating criteria and phases of pandemic reopening

| Phase | Criteria |
|-------|----------|
| Phase 1 | Decrease in severity of identified COVID-19 cases enter phase 1 |
| Phase 2 | Continued downward trajectory of positive test results after entering phase 1 |
| Phase 3 | Continued downward trajectory of positive test results after entering phase 2 |
| Phase 4 | End of the pandemic |

ICU, Intensive care unit.

### ADAPTATIONS FOR SONOGRAFHERS AND ECHOCARDIOGRAPHY LABORATORY PROCESSES

The COVID-19 pandemic has required sonographers rapidly to change their work flow, personal safety measures, and examination protocols. The initial lockdowns decreased clinical volume so significantly that many sonographers had their hours flexed down and were at risk for being furloughed, raising personal financial stresses. Subsequently, as laboratories and clinics expand services, the drive to “catch up” on the accumulation of deferred examinations places different physical and emotional stresses on sonographers and laboratory personnel. The increase in number of patients coming to the echocardiography laboratory is occurring concurrently with resumption of complete, comprehensive echocardiographic examinations with longer scan times. Young children remain less compliant with facemasks and have difficulty cooperating, particularly during the long examinations necessary to evaluate complex congenital heart disease. Optimal social distancing is difficult or impossible to achieve in a small echocardiography examination room with a child, caretaker, and sonographer. Some sonographers considered at high risk for COVID-19 have chosen to stay home, leaving fewer on-site sonographers to tackle an increased workload. Sonographer availability is also limited by the quarantine required when suspicious symptoms arise or a COVID-19 exposure occurs. All of these factors can lead to sonographer exhaustion and burnout, similar to what is observed in other frontline providers. To minimize this fatigue, measures to ensure
appropriate patient workload and adequate rest between cases should include:

- staggered scheduling with lengthened, dedicated time between echocardiography appointments and
- daily and weekly rotating shift adjustments.

To maintain personal safety for sonographers, patients, families, echocardiography and clinic personnel the following measures should be employed:

- mandatory use of masks for age-appropriate patients and their caretakers at all times;
- universal use of personal protective equipment (PPE; including eye protection) for the sonographer and ancillary staff as per the reintroduction statement, the levels of PPE used will depend on the phase of the response, local institutional policies, and COVID-19 testing status;
- limiting caretakers to one individual per patient when possible;
- maintaining meticulous sanitation protocols for machines, probes, rooms, and workstations; and
- social distancing in waiting areas or staggered entrance to the hospital for echocardiography appointments using text messaging.

Enhanced communication remains paramount and can markedly improve the physical and emotional effects of the pandemic for sonographers. The indications and goals for each scan should be clearly communicated among referring physicians, echocardiography faculty members, and sonographers. This communication and the development of focused lesion-specific protocols help the sonographer perform studies that obtain all the required information with minimal scan and exposure time. Echocardiography laboratory leadership must be constantly proactive in adjusting protocols and staffing, as risk levels change with the highly fluid nature of this pandemic.

Leadership decisions must be communicated to physicians and sonographers in real time to ensure that teams retain confidence that their welfare and the welfare of the patients and families is the highest priority. In return, sonographers encouraging their sonographer colleagues to communicate openly regarding their physical and mental health will assist in developing strategies for coping and adjusting to evolving echocardiography laboratory operations.

**FETAL ECHOCARDIOGRAPHY**

For fetal cardiology providers, the priority at the onset of the pandemic was to minimize the exposure of pregnant women and fetuses to SARS-CoV-2. The previous ASE statement described a triaging system for scheduling fetal echocardiographic examinations and consultations considering the risk for congenital heart disease, significant fetal arrhythmia, or anomaly by referral indication while keeping in mind the scheduling limitations imposed by a finite gestational period for pregnancy decision-making and perinatal and neonatal management planning. This triaging system resulted in a rapid decrease in fetal cardiology visits at multiple centers (by approximately 20%–35%) and decreased referrals. As a consequence, less face-to-face counseling occurred. When in-person visits did occur, they often did so with a single or even no support person accompanying the pregnant mother, even in the setting of a new diagnosis of a significant fetal congenital heart defect. Depending on local conditions, some centers began to resume more normal fetal cardiology scheduling practices and allow more support persons to accompany the patient. Reexpansion of fetal cardiology services has been highly variable, however, with some centers continuing to restrict services and see fewer referrals, with concomitant lower volumes and persistently decreased sonographer hours. Furthermore, with increases in infection rates, other centers may reinstate more restrictive strategies.

Without question, pregnant mothers have experienced increased psychosocial stress related to regulations limiting in-person support during fetal cardiology consultations. Pregnancy itself creates a higher risk state for COVID-19-related complications. SARS-CoV-2 testing of pregnant women has become standard practice before delivery, given the 10% rate of positive test results in asymptomatic women. For neonates born to SARS-CoV-2-positive mothers, the greatest risks at present appear to be preterm labor and fetal distress. Fortunately, there have been only a few reported cases of perinatal transmission of SARS-CoV-2, with most affected babies being asymptomatic. There are rare reports of placental infection and abnormalities, along with stillbirths in fetuses of pregnant women who are SARS-CoV-2 positive but asymptomatic. Thus far, there have been no reports of associated neonatal cardiac disease or documented fetal anomalies from early second trimester maternal COVID-19.

Moving forward, our better knowledge of risks and enhanced strategies for protection of sonographers and pregnant women has allowed the reexpansion of fetal cardiology services, while minimizing any negative impact of these strategies on holistic patient care. For example, if local obstetric and maternal-fetal medicine clinicians accurately perform fetal cardiac screening for low-risk indications, this strategy could continue, especially if images are available for review by the fetal cardiology providers if needed. It is critical, however, for certain patients to be scanned by a fetal cardiology team with in-person consultation for appropriate assessment and management. These patients include those at high risk for fetal congenital heart disease, those already diagnosed or suspected to have complex fetal cardiac diagnoses, hydrops fetalis, significant extracardiac anomalies, fetal anomalies requiring intervention or affecting the fetal heart, or significant fetal arrhythmias.

Telemedicine has become a valuable tool in fetal cardiology, with myriad possible applications offering maximum flexibility.
Telemicine fetal cardiology consultation can occur after the fetal cardiologist has reviewed images performed by obstetric and maternal-fetal medicine clinicians for low-risk indications or after review of images done in a fetal cardiology clinic or echocardiography laboratory. Telemicine can allow remote counseling for a new diagnosis or follow-up for congenital heart disease. With restrictions still in place on the number of family members or other support persons a pregnant woman can bring to the appointment, telemicine can allow those crucial support persons to join the patient during her in-person consult. The availability of telemicine has also enhanced options for multidisciplinary counseling. Additional providers such as genetic counselors, other fetal or pediatric subspecialties, and ancillary support such as social work and/or the palliative care team can join the consultation without compromising social distancing practices. These multiple benefits will continue to be realized as a lasting approach for comprehensive fetal cardiology care after the pandemic ends.
A proposed strategy for reexpansion of fetal cardiologic services adapting the previously published triage system and the CDC pandemic phases is delineated in Table 2 and Figure 1. In this new strategy, pregnant women in the moderate-risk and low-risk categories are added slowly back sequentially as societal viral burden decreases and regulations loosen.

PROCEDURAL SEDATION AND ANESTHESIA

The indications for procedural sedation and anesthesia remain largely unchanged from previous recommendations.1 On the basis of the high risk for aerosolization with transesophageal echocardiography, especially in patients with unsecured airways, preprocedural testing for SARS-CoV-2 is strongly recommended for all cases. However, preprocedural testing should not lead to any degree of complacency with risk reduction strategies, given the varied available testing options, the interpretation of the results on the basis of type of test, and the possible development of symptoms or infection during the intervening time from test to procedure. The removal of airborne or contact isolation precautions after a positive test result, in consultation with infectious disease experts, will alter the choice of procedural precautions. Institutional protocols to define those patients requiring airborne isolation, contact isolation, or no isolation are expected to continue to evolve as more individuals acquire immunity via disease or vaccine administration.

Transesophageal Echocardiographic Algorithms

An algorithm for transesophageal echocardiographic procedures was outlined in the ASE guidance document for pediatric and fetal echocardiography.1 Sedation and anesthesia personnel should continue to follow existing society guidelines and institutional protocols.2,3 The risk for transmission of SARS-CoV-2 from known infected patients to health care workers who adopt adequate precautions is low. Separate procedural rooms are recommended for patients requiring airborne isolation precautions with minimal staffing for procedures with aerosolization risk such as intubation, extubation, and transesophageal echocardiography with an unsecured airway.24 Contact precautions (gloves, gown, facemask) may be adequate for those patients who have previously tested positive but are not considered airborne risk.25 Additionally, standard precautions for all sedation and anesthesia requiring procedures should include gloves and facemasks at a minimum, with strict attention to hand hygiene before and after the procedure.
effectiveness of virtual education for some aspects of learning will mean that this modality is here to stay. Elements for successful and safe echocardiography training combining a hybrid model of virtual and hands-on clinical training are outlined in Table 3.

### MULTISYSTEM INFLAMMATORY SYNDROME IN CHILDREN

The emergence of a severe multisystem inflammatory syndrome with features similar to those seen in Kawasaki disease (KD) and toxic shock syndrome, frequent hemodynamic instability, and association with previous COVID-19 infection in otherwise previously healthy children was first reported in the United Kingdom on April 26, 2020. The CDC case definition for MIS-C is provided in Table 4. In the United States as of the last update posted by the CDC on January 8, 2021, there have been 1,659 reported cases and 26 deaths. Most children were 1 to 14 years of age (average, 8 years), but cases were reported in infants <1 year of age as well. More than 75% of children were Hispanic/Latino or non-Hispanic black. MIS-C in patients with known preexisting congenital or acquired heart disease has not been reported to date.

Cardiac involvement may manifest in three predominant and overlapping presentations: atypical KD-like spectrum (with particularly prominent gastrointestinal symptoms), vasodilatory or hyperinflammatory shock, or cardiogenic shock from impaired ventricular function. Given the potential for pancarditis, there should be a low threshold for performing or repeating echocardiography, with indications for echocardiography outlined in Table 5 and the essential elements of an MIS-C echocardiographic study presented in Table 6.

Ventricular dysfunction may range from mild to severe. As measured by ejection fraction, 33% to 75% of patients with MIS-C have ventricular dysfunction, with an even higher prevalence (90%) of dysfunction detected by global longitudinal strain. The ventricle may also be affected. Regional abnormalities have been noted, including apical hypokinesis resembling Takayasu cardiomyopathy. Diastolic impairment has been reported with abnormal findings on Doppler tissue imaging. Other cardiac findings have included pericardial effusion in about 8% to 25% of patients, mitral valve insufficiency in 50%, and greater than physiologic tricuspid valve insufficiency in 60%. Coronary artery dilation has been described in 6% to 24% of patients, although true aneurysms are quite unusual. Thrombus formation has been noted in the setting of severely depressed ventricular function, severe coronary artery dilation, or pulmonary embolism, although this complication appears to be less prevalent in MIS-C as opposed to the thromboembolic phenomena and coagulopathy reported in acute COVID-19 infections in adults.

Serial echocardiographic examinations are warranted during the acute illness, as ventricular function can worsen precipitously in the first 24 to 48 hours after admission, which is often around day 7 of illness. Timing of studies should be guided by clinical status in individual patients, but if ventricular dysfunction is present, repeat assessment is warranted at least every 5 to 7 days. Fortunately, in most patients ventricular function improves after therapy and supportive care, but residual dysfunction can persist at the time of discharge, with abnormal global longitudinal strain potentially persisting even after ejection fraction normalizes. If coronary artery dilation is present, serial echocardiograms should be obtained following the KD guidelines.

### ROLE OF ECHOCARDIOGRAPHY AND MULTIMODALITY IMAGING IN MIS-C FOLLOW-UP

Recommendations for mid- and long-term cardiac imaging are still evolving for MIS-C, depending on the clinical course and the severity and type of residual cardiac involvement at time of discharge. Careful follow-up is essential as we continue to learn more about this disease. One proposed strategy is for cardiology follow-up with echocardiography at 7 to 10 days after the onset of illness, 4 to 6 weeks, 4 to 6 months, and 9 to 12 months. More frequent follow-up would be necessary if there is marked coronary dilation, again using the KD guidelines. Long-term follow-up with stress echocardiography should be considered for those with chronic changes in ventricular function or coronary artery involvement.
Cardiac magnetic resonance imaging (MRI) may be useful in patients with MIS-C to further quantify ventricular function and assess for myocardial edema or scar or fibrosis. The best timing for cardiac MRI is not yet clear; however, MRI at 2 to 6 months in recovery could play a pivotal role in determining when patients with MIS-C may safely return to active play and sports. Following KD guidelines, cardiac computed tomographic angiography may be useful during either the acute or the follow-up phase to assess coronary artery involvement, progression of dilation, or suspected coronary thrombosis.36

Vascular Function in Patients with MIS-C

There is growing recognition that MIS-C includes a component of vascular injury, similar in concept if not necessarily pathophysiology to the vascular injury seen in adults with COVID-19. However, the newness of the disease makes the long-term implications of MIS-C in children unclear. In the acute setting, multiple inflammatory markers are elevated, including erythrocyte sedimentation rate, C-reactive protein, ferritin, alanine aminotransferase, fibrinogen and D-dimer levels, with accompanying lymphocytopenia, neutrophilia, anemia, thrombocytopenia, hypoalbuminemia, and a prolonged international normalized ratio.12 It remains to be seen if this widespread inflammation will permanently affect endothelial function and put these children at risk for adult cardiovascular disease over time. If MIS-C behaves in a similar fashion to KD or other inflammatory diseases, there is certainly concern for the development of accelerated atherosclerotic disease in this population. In the long-term follow-up of patients affected by MIS-C, vascular function assessment such as brachial artery reactivity testing and measurement of carotid intima-media thickness should be considered.

ROLE OF ECHOCARDIOGRAPHY AND MULTIMODALITY IMAGING IN LONG-TERM CARE AND RETURN TO AGE-APPROPRIATE ACTIVITY AND ATHLETICS IN PATIENTS WITH COVID-19

Most pediatric patients with mild COVID-19 infection are asymptomatic at short-term follow-up. However, a subset may experience persistent cough, dyspnea, chest discomfort, or palpitations long after resolution of acute infection.37 The American Academy of Pediatrics in conjunction with the CDC currently recommends that pediatri- cians screen children after acute COVID-19 infection for these symptoms before authorizing return to sports and athletics.40 If symptoms are present, rest and referral to pediatric cardiology is recommended given the possibility that subclinical myocarditis or myocardial injury occurred during the acute illness.

Strategies for the evaluation of young athletes to determine their eligibility to return to organized sports have been proposed by the American College of Cardiology and other organizations and include echocardiography, electrocardiography, stress testing, and possibly cardiac MRI depending upon the severity of symptoms and the results of other testing.39-42 The degree of evaluation needed for children to return to physical education classes and other age-appropriate activities has not yet been established but is likely to parallel the assessment for athletics. Echocardiographic examinations in patients recovered from COVID-19 infection should focus on assessing left and right ventricular function completely (including assessment of global longitudinal strain), the presence and degree of coronary artery dilation, and valve function. The range of adjunct diagnostic testing recommended from institution to institution is broad, and therefore until standardized guidelines are developed, each practice must develop its own as deemed appropriate. As long-term immunity to COVID-19 infection may not be universal, all studies should be performed using institution-specific recommendations for patients with unknown SARS-CoV-2 status unless preprocedural testing is obtained.

CONCLUSION

As with any new disease, the long-term course of COVID-19 and associated MIS-C is largely unknown. The above recommendations are based upon very limited short-term and midterm data and upon our understandings of disease processes thought to be similar. We will need continued observation, meticulous investigation, creativity, and a high degree of flexibility in order to be able to provide the best patient care and effectively train our fellows and sonographers while remaining safe during this pandemic. With vaccine distribution having begun recently, we look forward to eventually moving beyond the pandemic and returning to some more normal processes. This is unlikely, unfortunately, to be in the near future as the pandemic continues to evolve with recent strong surges. Some strategies that have been developed and successfully deployed during this time should continue now and beyond the pandemic, such as telemedicine for fetal cardiology consultation and video conferences allowing readily available access to webinars, national meetings, and remote local teaching and echocardiogram review. Reliance on the development of expert guidelines and standards, such as those developed by the ASE, will be essential to create a safe and effective environment for staff members, patients, and families.

Through it all, collaboration with peers and colleagues across the country has proved to be a bedrock and an essential resource for our pediatric, congenital, and fetal cardiology community.

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