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COVID-19: Implications for Audiology Practice

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COVID-19: IMPLICATIONS FOR AUDIOLOGY PRACTICE

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ABSTRACT

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Coronavirus Disease 2019, or COVID-19, emerged in Wuhan, China in December 2019 and quickly became an international public health emergency. COVID-19 was declared a worldwide pandemic in March 2020 and has spread throughout the globe (Balkhair, 2020). COVID-19 manifests in the body in a myriad of ways, ranging from no symptoms at all to critical illness or death. COVID-19 infection can have long-lasting, widespread effects on the human body, including the auditory and vestibular systems. Despite preventative efforts, COVID-19 patients have presented to audiologists with complaints of hearing loss, tinnitus, and vertigo. Audiologists need to be aware of the reported auditory and vestibular effects of COVID-19 infection in order to best assess and manage this population.

The purpose of this project is to identify the reported auditory and vestibular effects of COVID-19 to create an evidence-based recommended clinical protocol for audiologists for evaluating and treating patients affected by COVID-19. COVID-19 may be associated with sensorineural, sudden sensorineural, or conductive hearing losses, new or increased tinnitus, auditory processing difficulties, dizziness and nystagmus, and other vestibular pathologies. The audiometric or vestibular test battery performed on a COVID-19 patient is dependent on the patient's chief complaint, onset of symptoms, and whether or not the patient is currently COVID-19 positive. As the literature continues to expand on the auditory and vestibular effects of

COVID-19, audiologists need to stay informed on how to best meet the needs of current and recovered COVID-19 patients.

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LIST OF ABBREVIATIONS

AAA	American Academy of Audiology
ABR	Auditory Brainstem Response
ACE2	Angiotensin-Converting Enzyme 2
APD	Auditory Processing Disorder
ASHA	American Speech-Language Hearing Association
BPPV	Benign Paroxysmal Positional Vertigo
cVEMP	Cervical Vestibular Evoked Myogenic Potential
CDC	Center for Disease Control and Prevention
COVID-19	Coronavirus 2019
CQ	Chloroquine
CRP	C-Reactive Protein
DPOAE	Distortion Product Otoacoustic Emission
EUA	Emergency Use Authorization
FDA	Food and Drug Administration
GBS	Guillain-Barre Syndrome
GGO	Ground-Glass Opacifications
HCQ	Hydroxychloroquine
HHS	Health and Human Services
ICU	Intensive Care Unit
mAb	Monoclonal Antibodies

MERS-CoV	Middle East Respiratory Syndrome Related Coronavirus
NIAID	National Institute of Allergy and Infectious Diseases
NIH	National Institute of Health
oVEMP	Ocular Vestibular Evoked Myogenic Potential
OAE	Otoacoustic Emission
OSHA	Occupational Safety and Health Administration
OTC	Over the Counter
PPE	Personal Protective Equipment
RNA	Ribonucleic Acid
RT-PCR	Reverse Transcription-Polymerase Chain Reaction
SARS-CoV	Severe Acute Respiratory Syndrome Related Coronavirus
SARS-CoV-2	Severe Acute Respiratory Syndrome Related Coronavirus 2
SAS	Self-Rating Anxiety Scale
SSNHL	Sudden Sensorineural Hearing Loss
TEOAE	Transient Evoked Otoacoustic Emission
THI	Tinnitus Handicap Inventory
VEMP	Vestibular Myogenic Evoked Potential
vHIT	Video Head Impulse Test
VNG	Videonystagmography
VRT	Vestibular Rehabilitation Therapy
WHO	World Health Organization

CHAPTER I

REVIEW OF THE LITERATURE

Coronavirus Disease

On January 30, 2020, the World Health Organization (WHO) declared the novel coronavirus disease an international public health emergency and a pandemic on March 11, 2020 (Balkhair, 2020). Coronavirus Disease 2019 or COVID-19 (previously known as 2019-nCoV) (McIntosh, 2021) has quickly become one of the worst pandemics in human history (Balkhair, 2020). Wuhan, China is largely considered to be this new disease's place of origin due to a large number of pneumonia cases that suddenly appeared. However, it has recently been documented that the virus that causes COVID-19 is thought to have been active outside of China as well (Platto et al., 2021). While the virus may have existed outside of China first, it had remained dormant until it encountered conditions that led to its outbreak in Wuhan in December 2019. COVID-19 has widespread effects in the human body, some of which include damage to the auditory and vestibular systems. It is important for audiologists to understand these potential complications in order to better treat their patients.

Coronaviruses

Coronaviruses are positive, single-stranded, enveloped ribonucleic acid (RNA) viruses that typically cause mild to moderate upper-respiratory tract infections (National Institute of Allergy and Infectious Diseases [NIAID], 2021). These viruses get their name from the Latin word "corona," which means crown (Chowdhury & Oommen, 2020), referring to the crown-shaped spike proteins that are present on their surface (Alsobaie, 2021).

Coronaviruses belong to the *Coronaviridae* (CoV) subfamily of the *Coronavirinae* family of RNA viruses. The *Coronaviridae* subfamily includes alpha, beta, gamma, and delta classes of coronaviruses (Platto et al., 2021). Alpha- and beta-coronaviruses circulate primarily in bats and mammals, whereas the gamma- and delta-coronaviruses circulate in birds. Alpha-coronaviruses generally result in mild or asymptomatic infections and beta-coronaviruses can cause more severe or fatal infections (Velavan & Meyer, 2020).

There are hundreds of coronaviruses, but only seven are known to infect humans (NIAID, 2021). Four of the seven commonly infect humans and cause mild to moderate infection: 229E and NL63, which are alpha-coronaviruses, and OC43 and HKU1, which are beta-coronaviruses (Alsobaie, 2021; Centers for Disease Control and Prevention [CDC], 2020a). The other three known human coronaviruses have emerged recently and have caused serious, widespread infection in humans: severe acute respiratory syndrome related coronavirus (SARS-CoV), Middle East respiratory syndrome related coronavirus (MERS-CoV), and severe acute respiratory syndrome related coronavirus 2 (SARS-CoV-2) (Platto et al., 2021).

Severe acute respiratory syndrome related coronavirus, or SARS-CoV, emerged in November 2002 and disappeared by 2004. SARS-CoV spread rapidly across 26 countries within a few months through infected travelers. More than 8,000 people contracted the virus, and 774 died. In September 2012, Middle East respiratory syndrome, or MERS-CoV, was identified. MERS-CoV was transmitted to humans from an animal reservoir in camels. Sporadic, localized outbreaks of this disease still occur today (NIAID, 2021).

COVID-19

Severe acute respiratory syndrome coronavirus 2, or SARS-CoV-2 emerged in December 2019, and causes coronavirus disease 2019, or COVID-19 (NIAID, 2021). Genomic

sequence studies have shown that SARS-CoV-2 is 50% similar to MERS-CoV and 77% similar to SARS-CoV (Dasgupta et al., 2020). Due to the previous research on SARS-CoV and MERS-CoV, researchers were able to determine how SARS-CoV-2 infects a host cell within only two weeks of discovering COVID-19 (NIAID, 2021). SARS-CoV-2 enters host cells by binding to the angiotensin-converting enzyme 2 (ACE2) receptor protein. The ACE2 receptor protein is located on the cell's surface, which allows the virus to fuse to the host cell after binding. From here, virus transcription occurs, and the virus is able to replicate, and the infection can spread throughout the body (Alsobaie, 2021).

Zoonosis. The SARS-CoV-2 virus has been classified as zoonotic, meaning that it can be transmitted from vertebrate animals to humans (Haider et al., 2020). Zoonotic diseases occur as a result of a decrease in ecosystem biodiversity due to the change of natural habitats into agriculture or urban ecosystems by humans. This, in turn, increases the contact between humans and animals. Zoonotic diseases are becoming increasingly more common as human contact with animal reservoirs that may carry pathogens has become more common as well. An animal reservoir occurs when an infection is maintained in an animal's population, but is able to infect humans, serving as a continuous source of human infection (Haider et al., 2020). Biodiversity, or a large number of different species, acts as a buffer against pathogen transmission and the persistence of pathogens. This is known as the "dilution effect." The dilution effect has decreased in recent years due to human activity in ecosystems, which can increase the risk of an animal-born pathogen infecting humans (Platto et al., 2021). Due to the reduction in the dilution effect, viruses are able to jump from animal reservoirs to humans. When this happens, it is called a spillover event (NIAID, 2021). In the last 20 years, there have been three events of widespread

zoonotic transmission and spillover events of infections from animals to humans: SARS-CoV, MERS-CoV, and SARS-CoV-2 (Alsobaie, 2021).

Although no animal reservoir responsible for the transmission has been officially declared, bats are the most likely source (Alsobaie, 2021; Platto et al., 2021). It is thought that bats are the most likely reservoir of SARS-CoV-2 because SARS-CoV-2 is 96% identical to the genome of a common coronavirus in bats: BatCov RaTG13 (Alsobaie, 2021; Velavan & Meyer, 2020). Now that the virus has been transmitted from animal to human, it can easily be spread from person to person.

Human Transmission. How effectively a virus can spread through a population is dependent on its basic reproduction number and secondary attack rate. The number of secondary cases that could arise from a single infected individual is known as the virus' basic reproduction number (R0). R0 is useful in disease epidemiology for estimating epidemic spread. For SARS-CoV-2, this number is estimated to be between 2.0 and 3.0, meaning that one infected individual has the potential to infect two to three other individuals. Another key component in disease infectivity is the secondary attack rate, which is the probability of an infection occurring in a group of susceptible individuals who are exposed from a single case, such as a household or other close contact. In the United States, the secondary attack rate is estimated to be around 10.5%. The incubation period, or the time after being exposed to a virus until symptoms arise, for SARS-CoV-2 is anywhere between 2.2 to 11.5 days (Chowdhury & Oommen, 2020).

SARS-CoV-2 is highly contagious and can be spread by both direct and indirect contact. Indirect contact includes contaminated objects and air, and direct contact includes droplet and human-to-human transmission. Direct contact is the most common way that the virus spreads. Droplets typically can't travel more than six feet and typically only stay in the air for a short

amount of time. However, SARS-CoV-2 can remain suspended in the air for up to three hours. The best way to limit aerosol spread is with disinfectant and increased room ventilation. A person can become infected with COVID-19 if they touch a surface that has been contaminated with the virus and then touch any mucous membrane, like the eyes, mouth, or nose.

The time in which an individual with COVID-19 can continue to spread the virus is unclear at this time. The highest viral load in oropharyngeal secretions has been noted in the early symptomatic stage of the infection, however, individuals can continue to shed the virus after symptoms resolve. The virus continues to shed in stool up to four weeks after respiratory samples come back negative. More severe cases tended to result in a prolonged period of viral shedding after symptom resolution (Chowdhury & Oommen, 2020). The SARS-CoV-2 virus can also spread from individuals who are asymptomatic or from individuals who are not yet symptomatic but are within the virus's incubation period (Lofti et al., 2020). In one study, 6.4% of the COVID-19 infections reported were thought to be the result of pre- or asymptomatic transmission (Wei et al., 2020).

COVID-19 in Humans

Epidemiology of COVID-19

As of April 23, 2023, the World Health Organization reports 763,740,140 confirmed COVID-19 cases, including 6,908,554 deaths. Of these cases, 102,977,396 and 1,120,529 of the deaths have occurred in the United States alone (WHO, 2022b). Worldwide case data can be found in Table 1 and Figure 1. Figure 2 contains case data for the United States, and Figure 3 contains Colorado case data. Note that each figure utilizes a different scale on the y-axis to display case counts. The actual number of cases is likely much higher than this, since many cases went undiagnosed, or individuals tested positive with an at-home test and did not report their

results to health departments or hospitals, meaning that even more people may have been impacted by COVID-19 than these figures and case counts would suggest.

Table 1

Cumulative Global COVID-19 Cases and Deaths Over Time

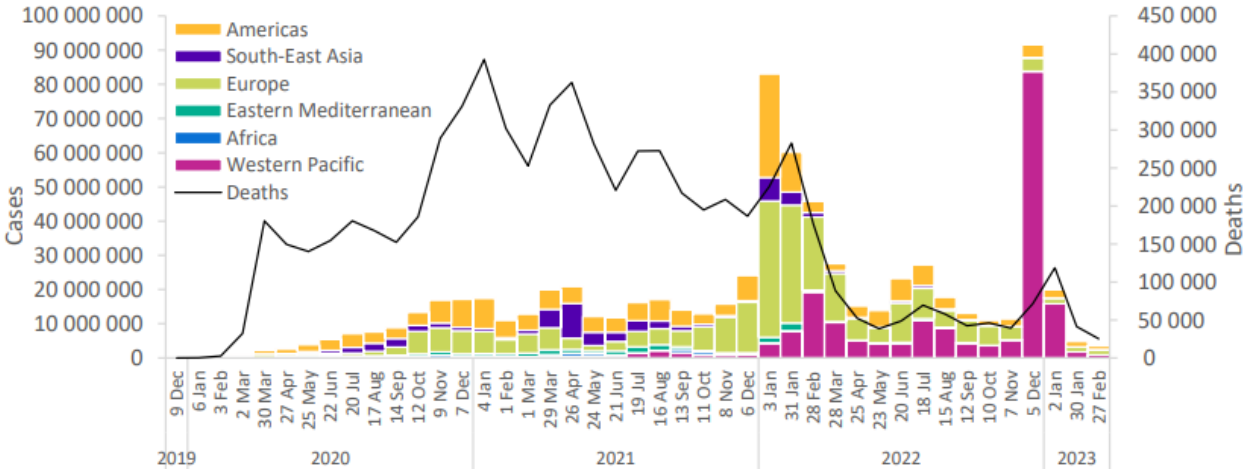
Date	Cases	Deaths
December 2019[a]	27	0
March 2020	750,890	36,405
June 2020	10,185,374	503, 862
September 2020	32,730,945	991,224
December 2020	79,321,893	1,754,574
March 2021	126,372,442	2,769,696
June 2021	180,492,131	3,916,771
September 2021	231,416,660	4,741,330
December 2021	278,714,484	5,393,950
March 2022	479,311,589	6,122,118
June 2022	541,313,815	6,327,547
September 2022	612,234,191	6,515,947
December 2022	656,398,043	6,672,752
March 2023	761,321,408	6,886,489

Note. Adapted from "Coronavirus disease (COVID-19) weekly epidemiological updates and monthly operational updates," by the World Health Organization, 2023. (https://www.who.int/emergencies/diseases/novel-coronavirus-2019/situation-reports).

[a] Adapted from "The first 50 days of COVID-19: A detailed chronological timeline and extensive review of literature documenting the pandemic" by Z. Allam, 2020, *Surveying the COVID-19 Pandemic and its Implications* (1-7). (https://doi.org/10.1016/B978-0-12-824313-9.00001-2).

Figure 1

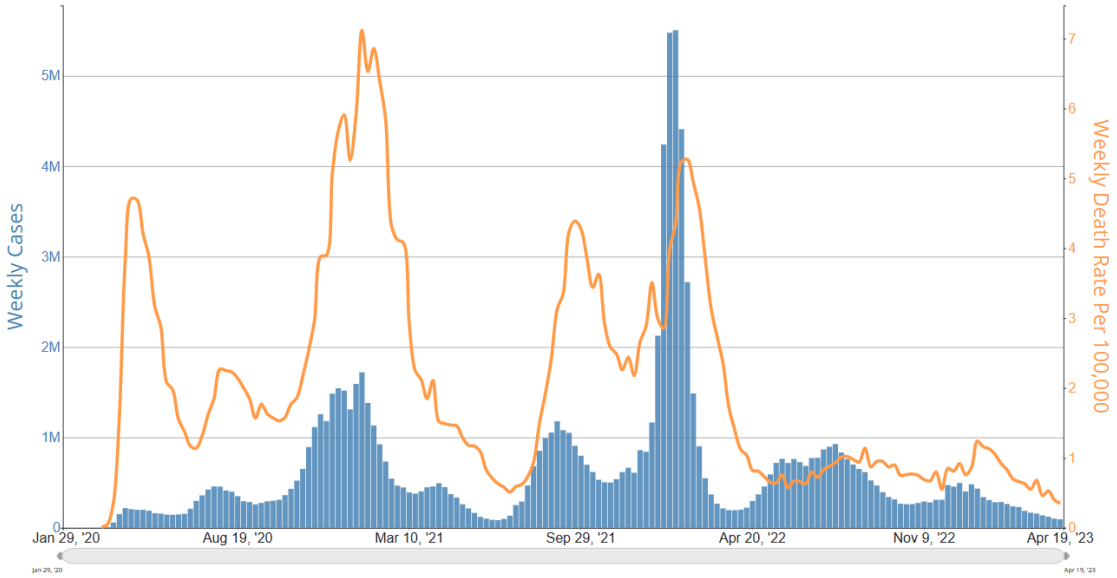
Global COVID-19 Cases Reported by the World Health Organization as of August 5, 2022.



Note. From "Coronavirus disease (COVID-19) weekly epidemiological updates and monthly operational updates" by the World Health Organization, 2022 (https://www.who.int/emergencies/diseases/novel-coronavirus-2019/situation-report). In the public domain.

Figure 2

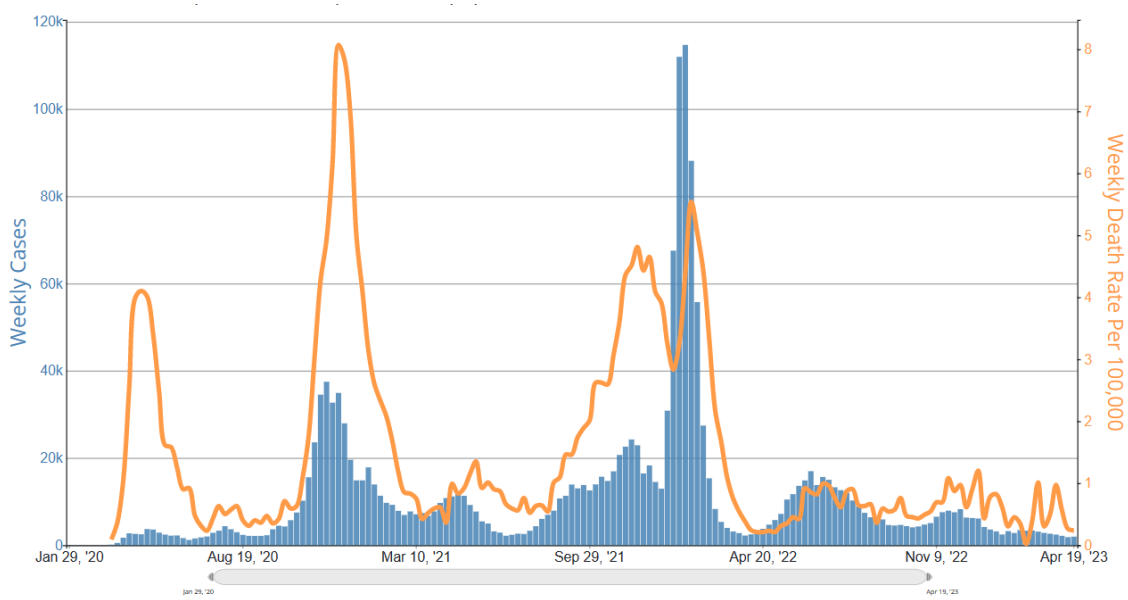
COVID-19 Cases in the United States of America Reported by the Centers for Disease Control and Prevention as of April 23, 2023.



Note. From "COVID-19 data tracker" by the Centers for Disease Control and Prevention, 2023 (https://covid.cdc.gov/covid-data-tracker/#trends_weeklycases_7daydeathsper100k_00). In the public domain.

Figure 3

COVID-19 Cases in Colorado Reported by the Centers for Disease Control and Prevention as of April 23, 2023.



Note. From "COVID-19 data tracker" by the Centers for Disease Control and Prevention, 2023 (https://covid.cdc.gov/covid-data-tracker/#trends_weeklycases_7daydeathsper100k_00). In the public domain.

COVID-19 infections can occur in individuals of any race/ethnicity, sex, or age. As shown in Figure 4, in the United States, individuals who are American Indian, Alaskan Native, Asian, Black, or Hispanic are at an increased risk of contracting COVID-19, hospitalization, and death compared to White, Non-Hispanic individuals. Different races and ethnicities may be risk markers for other factors that may contribute to this increased risk, such as underlying health conditions, socioeconomic status, healthcare access, and occupation-related exposure (CDC, 2022c).

Figure 4

COVID-19 Risk by Race/Ethnicity

Rate ratios compared to White, Non-Hispanic persons	American Indian or Alaska Native, Non-Hispanic persons	Asian, Non-Hispanic persons	Black or African American, Non-Hispanic persons	Hispanic or Latino persons
Cases[1]	1.6x	0.7x	1.1x	1.5x
Hospitalization[2]	3.1x	0.8x	2.4x	2.3x
Death[3]	2.1x	0.8x	1.7x	1.8x

Note. From "Hospitalization and death by race/ethnicity" by the Centers for Disease Control and Prevention, 2022c (https://www.cdc.gov/coronavirus/2019-ncov/covid-data/investigations-discovery/hospitalization-death-by-race-ethnicity.html). In the public domain.

Variants

The virus that causes COVID-19 has continuously evolved over time, creating new variants. These new variants are created as a result of changes to the virus' genetic code during replication. SARS-CoV-2 genetic lineages are identified in scientific research by Pango lineages, GISAID clades, or Nextstrain clades. The World Health Organization recommended that SARS-CoV-2 variants be named using Greek Alphabet letters, in order to ease public discussions of variants (WHO, 2022a). According to the CDC, variants may be classified as variants being monitored (VBM), variants of interest (VOI), variants of concern (VOC), or variants of high consequence (VOHC), depending on their individual characteristics and prevalence (CDC,

2022b). The WHO classifies variants as variants of concern (VOC), variants of interest (VOI), or variants under monitoring (VUM) (WHO, 2022a). VOIs, VUMs, and VBMs are variants that are circulating at minimal levels, or may be undetectable, and do not pose a significant risk to public health (Aleem et al., 2022).

There have been multiple variants of SARS-CoV-2 reported over time. Five variants have been considered variants of concern (VOCs) at some point in time due to their impact on public health. Variants that have been classified as VOCs are Alpha, Beta, Gamma, Delta, and Omicron (Aleem et al., 2022). As of October 27th, 2022, the only variant that still has the VOC classification is Omicron (CDC, 2021b), and Alpha, Beta, Gamma, and Delta are considered previously designated VOCs. The other SARS-CoV-2 variants (Epsilon, Zeta, Eta, Theta, Kappa, Lambda, and Mu) have been classified as VOIs (Aleem et al., 2022).

Symptomatology

COVID-19 can manifest itself in a variety of ways, ranging from no symptoms to critical illness. Symptoms generally appear within 2-14 days after COVID-19 exposure. Common acute symptoms of COVID-19 may include fever, chills, cough, shortness of breath, difficulty breathing, fatigue, muscle aches, headache, loss of taste or smell, sore throat, congestion, nausea, vomiting, and diarrhea in varying combinations and degrees depending on where the infection falls on the clinical spectrum. The cardiovascular system, gastrointestinal tract, kidney function, and liver function may be affected by SARS-CoV-2 as well (Lofti et al., 2020). COVID-19 has also been known to cause auditory and vestibular symptoms, such as hearing loss, tinnitus, and vertigo (Almufarrij et al., 2020).

The clinical spectrum of COVID-19 infections includes asymptomatic or pre-symptomatic infection, mild illness, moderate illness, severe illness, and critical illness.

Asymptomatic or pre-symptomatic infections occur when an individual tests positive for SARS-CoV-2 but is not experiencing any symptoms consistent with COVID-19 (National Institute of Health [NIH], 2021c). Individuals who have a mild illness may experience any of the typical symptoms of COVID-19, but without shortness of breath, dyspnea, or abnormal chest imaging. Individuals with moderate illness have evidence of lower respiratory disease on chest imaging and have an oxygen saturation level that is less than or equal to 94% (NIH, 2021c). Severe, emergency COVID-19 symptoms, which require immediate medical care, include severe trouble breathing, chest pain or pressure, confusion, inability to wake up or stay awake, and pale, gray, or blue skin, lips, or nail beds (CDC, 2021a). An individual is considered to have a severe illness when the oxygen saturation is less than 94%, the ratio of arterial partial pressure of oxygen to inspired oxygen is less than 300 mm Hg, the respiratory rate is less than 30 breaths per minute, or there are greater than 50% lung infiltrates. Critical illnesses occur when an individual has respiratory failure, septic shock, or multiple organ dysfunction (NIH, 2021a). A summary of the clinical spectrum of COVID-19 infections can be found in Table 2.

Table 2

Clinical Spectrum of COVID-19 Infection as defined by the National Institute of Health

Mild Illness	Moderate Illness	Severe Illness	Critical Illness
No shortness of breath or dyspnea	$SpO_2 \geq 94\%$ on room air at sea level	$SpO_2 \geq 94\%$ on room air at sea level $PaO_2/FiO_2 < 300$ mm Hg Respiratory rate > 30 breaths per minute	May cause acute respiratory distress syndrome, virus-induced distributive septic shock, cardiac shock, exaggerated inflammatory response, thrombotic disease, and exacerbation of underlying comorbidities
No abnormal imaging	Lower respiratory distress evident on imaging	Lung infiltrates >50%	
Outpatient or at home care	Pulmonary disease may progress rapidly Monitor	May rapidly deteriorate Requires oxygen therapy	Requires treatment in the ICU

Note. Adapted from "Clinical spectrum of SARS-CoV-2 infection" by the National Institute of Health, 2021c (https://www.covid19treatmentguidelines.nih.gov/overview/clinical-spectrum/).

Post-COVID Conditions

Many symptoms of COVID-19 do not resolve immediately after the infection has cleared, resulting in post-acute COVID-19 syndrome (Nalbandian et al., 2021). In a study by Stavem et al. (2020), 47% of females and 33% of males continued to experience symptoms 1.5 to 6 months after a COVID-19 infection. The most common symptoms to linger after the viral infection were difficulty breathing and loss or disturbance of taste or smell. Individuals who had

comorbid conditions and a high symptom load during the infection were more likely to experience persistent symptoms (Stavem et al., 2020).

The long-term complications of COVID-19 can be pulmonary, cardiovascular, hematologic, glucometabolic, gastrointestinal, neuropsychiatric, or dermatologic complications. Common long-term pulmonary conditions include dyspnea, hypoxia, decreased exercise capacity, restrictive pulmonary physiology, fibrotic changes, ground-glass opacities, and reduced diffusion capacity. Cardiovascular complications include increased cardiovascular disease, intra- and interlobular septum thickening, palpitations, chest pain, increased cardiometabolic demand, myocardial fibrosis, arrhythmias, tachycardia, and autonomic dysfunction. Hematologic complications, such as thromboembolic events, have been reported in less than 5% of individuals with post-acute COVID-19. The risk of hematologic complications increases with oral anticoagulant or heparin use. Glucometabolic complications include increased risk of dyslipidemia, hyperglycemia, and endocrinological issues, such as hypercortisolism, primary/central hypothyroidism, new or worsening diabetes mellitus, subacute thyroiditis, and bone demineralization. Gastrointestinal symptoms, such as prolonged viral fecal shedding, can occur. COVID-19 may also affect the microbiome in the gastrointestinal tract. Neuropsychiatric complications can be persistent musculoskeletal pain, femoral head necrosis, depression, post-traumatic stress disorder, panic disorder, chronic fatigue syndrome, somatoform pain disorder, and compromised quality of life. The most predominant symptom of post-acute COVID-19 syndrome is hair loss, which has been reported in 20% of survivors (Dasgupta et al., 2020; Nalbandian et al., 2021).

Screening Methods

Symptom Screening Questionnaires

Screening for COVID-19 symptoms can help identify individuals who should not enter a facility and should be tested. The Centers for Disease Control and Prevention utilizes a facility screening which asks about the presence of common COVID-19 symptoms in the last 48 hours, regardless of vaccination status. Individuals are encouraged to identify any symptoms they are experiencing, even if they believe that the symptoms are not caused by COVID-19 (CDC, 2020b). This model has been modified to form other questionnaires in hopes to identify individuals who may be infected with COVID-19 before they enter a facility and potentially infect others. These questionnaires focus on contact with an infected individual within the past 14 days, a history of overseas travel, fever, respiratory symptoms, severe muscle aches, diarrhea, or loss of taste or smell. If an individual answers “yes” to any of the questions, they are denied entrance into the facility and advised to get tested for the virus (Hur & Chang, 2020).

Screening questionnaires are thought to be effective ways to slow COVID-19 transmission by preventing infected individuals from coming in contact with others within a facility. However, when examining COVID-19 symptom screening questionnaires for air travel, Gostic and colleagues (2020) estimated that only one third to one half of the infected individuals will be identified with a questionnaire. It is also possible for individuals to be falsely flagged as positive by screening questionnaires. The recommendation is to have rapid COVID-19 tests available in travel scenarios to rule out false positives.

Viral Test Screening

In more high-risk settings, like long-term care facilities, screening for COVID-19 with viral testing is recommended so that infected individuals can be quarantined, close contacts can

be traced, and outbreaks can be prevented. Viral test screening can identify pre- or asymptomatic individuals, whereas the screening questionnaires cannot (McIntosh, 2021). Viral antigen tests are the most commonly used test for viral screening or for individuals with a known exposure to the virus due to its reliability in detecting earlier infections (CDC, 2021c).

Diagnosis

Standard Laboratory Measures

Clinical laboratory tests for COVID-19 patients include a complete blood count with differential and metabolic profile and liver and renal function tests (NIH, 2021c). Blood chemistry studies of patients with COVID-19 have shown increased white blood cell count (WBC), lactate dehydrogenase (LDH), aspartate aminotransferase (AST), alanine transaminase (ALT), C-reactive protein (CRP), creatine kinase (CK), erythrocyte sedimentation rate (ESR), D-dimer level, procalcitonin, urea, and creatine levels. Decreased hemoglobin, lymphocyte and eosinophil count, and serum albumin have been reported as well (Lofti et al., 2020). Inflammatory markers such as CRP, D-dimer, and ferritin are not routinely measured, but these measurements may have prognostic value (NIH, 2021c).

Radiology Measures

The best pulmonary imaging technique for individuals with COVID-19 has not yet been determined, but chest x-rays, ultrasound screenings, or computed tomography (CT) scans have been used. Electrocardiograms may also be performed if indicated (NIH, 2021c). Computed tomography (CT) findings in COVID-19 patients show the presence of ground-glass opacifications (GGO) and ground-glass opacifications with consolidations (Lofti et al., 2020) and crazy paving pattern (Lim et al., 2021). GGO refers to an area of hazy, increased opacity in the lungs where vessels and bronchial structures are still visible. GGO with consolidation occurs

when the lungs are so opaque that the vessels and bronchial structures are not visible (Infante et al., 2009). Crazy paving pattern refers to scattered ground-glass opacities with interlobular septal thickening and intralobular lines (Rossi et al., 2003). The distribution of lesions in the lungs can vary depending on the individual, the severity of the infection, and the phase of infection. The presence of GGO is often greater in the early phases of the disease, whereas the GGO with consolidations and crazy paving pattern occur in the later stages, as the virus further infiltrates the lungs. A higher degree of consolidation in the lungs that is visible with CT is often associated with more severe infections and poorer outcomes (Lim et al., 2021). Even individuals with mild COVID-19 infections may have severe pulmonary changes evident on radiography up to five or six weeks after recovery (Dror et al., 2020).

Covid-19 Testing for Current and Past Infections

An accurate way to diagnose COVID-19 infections quickly became necessary to discover the number of cases worldwide, nationally, and regionally and to determine the appropriate medical and government interventions for treatment and prevention. There are currently three different diagnostic tools used to detect SARS-CoV-2: viral gene detection, human antibody detection, and viral antigen detection (Yöce et al., 2021). These tools differ in terms of the ability to detect an active infection versus detection of a past infection or vaccine response.

Viral Gene Detection. The genes that make up the SARS-CoV-2 virus can be detected through the reverse transcription-polymerase chain reaction (RT-PCR) technique. This technique directly measures the viral genomic parts of a sample to look for SARS-CoV-2 (Yöce et al., 2021) and can diagnose a current COVID-19 infection (CDC, 2021e). Viral gene detection involves two consecutive reactions that allow for RNA detection: converting RNA into its complementary DNA sequence utilizing a reverse transcription enzyme and amplifying that

DNA sample with a polymerase chain reaction. This type of detection test requires swabs from the nasopharynx, oropharynx, respiratory tract, bronchoalveolar lavage, or sputum. Some of the RT-PCR kits for SARS-CoV-2 can be used at home, where an individual performs their own nasal swab and mails the sample off for testing. RT-PCR testing is currently the most reliable method for COVID-19 detection (Yöce et al., 2021).

On April 14, 2022, the FDA authorized a new COVID-19 diagnostic test for emergency use. This test detects COVID-19 chemical compounds in breath samples, called the InspectIR COVID-19 Breathalyzer. It is shown to have 91.2% sensitivity and 99.3% specificity. This test is designed to be used by healthcare professionals in doctor's offices, hospitals, or mobile testing sites (FDA, 2022c).

Human Antibody Detection. Antibodies are proteins that are produced by the immune system in response to an antigen. Different classes of antibodies are produced throughout the course of an infection: IgM, IgD, IgG, IgA, and IgE. The IgM class of antibody is the first one to be produced during an infection and the IgG class of antibody is the most abundant in the system. An antibody test can measure the IgM and IgG antibody levels in serum, blood, or plasma samples to determine if the body is fighting off a pathogen. The biggest issue with this type of test is the possibility of false positives and false negatives. A false positive test may occur as a result of cross-reactivity, which is when antibodies bind to an antigen that is not the target, due to similarities in the molecules. A false negative may occur if a test is taken too soon into an infection, since it may take the body up to one to three weeks to produce antibodies in response to a pathogen (Yöce et al., 2021). Because of this, antibody tests are generally not used to diagnose a current COVID-19 infection, but to detect a past infection. A positive antibody test

may also occur from vaccination against the virus that causes COVID-19, but antibody testing is not recommended to determine immunity to COVID-19 following vaccination (CDC, 2021e).

Viral Antigen Detection. Antigens are molecules that trigger an immune response and antibody production to kill off pathogens. A current COVID-19 infection can be detected through viral antigen tests, in which viral components or the virus itself can be detected without as many steps as other detection methods. Antigens are present and detectable before the antibodies are, and so viral antigen detection tests may be more reliable at detecting early infections. Because of this, this type of test is often useful as COVID-19 screening tests and for use in individuals with a known exposure to the virus (CDC, 2021c). However, this type of test is unable to differentiate between a SARS-CoV and a SARS-CoV-2 infection since these viruses are so closely related (Yöce et al., 2021).

The original antigen detection tests were designed to be used by healthcare professionals to collect nasal and nasopharyngeal swab samples (Yöce et al., 2021). There are now antigen detection tests available for at-home use, or at-home over the counter (OTC) tests. FDA authorized at-home tests are available online or in drugstores without a prescription. These tests are designed to be used for serial testing in people without symptoms or as a way to detect a current COVID-19 infection in individuals who began experiencing symptoms in the last five to seven days (FDA, 2022d).

Pharmacological Medical Treatment

Currently, most medical treatments for COVID-19 infections target symptom management, and not the virus itself, and depends on where on the clinical spectrum the infection falls (Lofti et al., 2020; NIH, 2021c). COVID-19 patients may experience complications, such as acute respiratory distress syndrome, or secondary infections. Treatment

for these conditions may include antibiotics, antiviral drugs, corticosteroids, and invasive mechanical ventilation. Experimental treatments have been used to attempt to defeat the COVID-19 virus itself, including monoclonal antibodies, peptides, Interferon-based therapies, protease inhibitors, and small-molecule drugs (Lofti et al., 2020). Drugs used most commonly in COVID-19 patients are monoclonal antibodies, antiviral drugs, immune modulators, sedatives, or renal replacement therapies (FDA, n.d.).

Anti-SARS-CoV-2 monoclonal antibodies (mAb), such as bamlanivimab plus etesevimab, casirivimab plus imdevimab, sotrovimab, and vilobelimab, have been shown to reduce risk of hospitalization and death in patients with mild to moderate COVID-19 infections. MAbs are antibodies produced in a laboratory that block entry into cells, which neutralizes the SARS-CoV-2 virus (FDA, n.d.). These products were granted emergency use authorization (EUA) by the Food and Drug Administration (FDA) on November 20, 2020 (FDA, 2020d). Monoclonal antibody products are generally reserved for use in individuals who are at higher risk for disease progression. Treatment for eligible individuals should begin as soon as possible after the patient receives a positive SARS-CoV-2 test and within 10 days of symptom onset (NIH, 2021d). Some monoclonal antibody treatments, such as tixagevimab plug cilgavimab (Evusheld) are designed for pre-exposure prophylaxis of COVID-19 in individuals who are severely immunocompromised or who have a history of severe allergy preventing COVID-19 vaccination (American Medical Association, 2022).

Remdesivir emerged in clinical trials as a potential antiviral treatment of COVID-19 only two months after discovery of the virus (NIAID, 2021). Remdesivir is a broad-spectrum antiviral treatment that has been used to treat Ebola in humans and both SARS-CoV and MERS in animal models (NIAID, 2020). The results of early clinical trials suggest that remdesivir is superior to a

placebo in shortening the recovery time of COVID-19 positive, hospitalized adults. Remdesivir is recommended for use in individuals who meet the criteria for severe illness. It is not recommended when not medically necessary to treat severe illness at this point in time, since there may be adverse effects when discontinuing the medication (Rochwerg et al., 2020). Since early studies found remdesivir to be effective in treating COVID-19, the FDA authorized it for emergency use on May 1, 2020 (Beigel et al., 2020; FDA, 2020a). The FDA fully approved remdesivir under brand name Veklury for use in individuals 12 years of age and older for hospitalized COVID-19 treatment on October 22, 2020 (FDA, 2020c).

Other antiviral medications are available to treat COVID-19 infection at home for those who are at risk of severe disease progression. Nirmatrelvir with Ritonavi (Paxlovid) and Molnupiravir (Lagevrio) are two antiviral medications that can be taken orally to treat COVID-19. Both medications should be taken within 5 days of when symptoms begin. Paxlovid is approved for use in adults and children aged 12 years and older, and Lagevrio is approved for adults only (CDC, 2022d).

With SARS-CoV-2, the immune system often becomes hyperactive, leading to worsening disease. Immune modulators, such as baricitinib and anakinra, function to activate, enhance, or, in the case of COVID-19 immune modulators, suppress the immune system. Baricitinib has received emergency use authorization by the FDA to be used in combination with remdesivir for treatment of COVID-19 infection in patients older than 2 years of age who require supplemental oxygen, mechanical ventilation, or extracorporeal membrane oxygen (ECMO) (FDA, n.d.). Anakinra has received emergency use authorization for the treatment of hospitalized COVID-19 patients with pneumonia who require supplemental oxygen and who are at high risk of progressing to severe respiratory failure (FDA, 2023).

Dexamethasone is a glucocorticoid that is thought to control inflammation-related lung injury and prevent respiratory failure in COVID-19 patients (Horby et al., 2021). Dexamethasone has been recommended for use in hospitalized patients who require mechanical ventilation (Horby et al., 2021; Mehta et al., 2021). Patients who are hospitalized and mechanically ventilated are shown to have lower 28-day mortality rates when treated with dexamethasone. Individuals who are hospitalized with COVID-19, but do not require respiratory support, do not benefit from dexamethasone treatment (Horby et al., 2021). However, the use of this drug is variable across hospitals, and up to one fifth of potentially eligible patients are not receiving the treatment (Mehta et al., 2021). Dexamethasone is not recommended to treat non-hospitalized patients with mild to moderate COVID-19 who do not require supplemental oxygen (NIH, 2021d).

Hydroxychloroquine (HCQ) and chloroquine (CQ) are anti-inflammatory treatments commonly used to treat rheumatic conditions and malaria (Mehta et al., 2021). HCQ and CQ were commonly used as a potential COVID-19 treatments in the early months of the pandemic but were abandoned shortly after due to ineffectiveness and potential harms (Mehta et al., 2021). Both HCQ and CQ have been found to cause serious cardiac adverse events and other serious side effects, including ototoxicity (De Luca et al., 2021) without producing any potential benefits. The known and potential benefits of these medications no longer outweighs the risks, and for these reasons the FDA revoked its emergency use authorization for the drug on June 15, 2020 (FDA, 2020b).

Other pharmaceuticals may be used in COVID-19 patients to maintain sedation or to treat complications. Propofol-Lipuro 1% and Fresenius Kabi Propoven 2% are the current FDA emergency use authorized sedatives for maintaining sedation in COVID-19 patients for

intubation and ventilation. SARS-CoV-2 complications may include kidney damage or failure. Due to shortages of traditional renal replacement therapies, alternative renal replacement therapies, such as regiocit replacement solution and Frenius Medical replacement solutions, have been authorized for emergency use in COVID-19 patients (FDA, n.d.). Table 3 summarizes the pharmacological treatment options for COVID-19 patients.

Table 3

Summary of pharmacological treatment options for COVID-19 patients as of April 23, 2023.

Pharmaceutical	Type of Drug	FDA Approval
Actemra (tocilizumab)	Immune Modulator/ Monoclonal Antibody	EUA – June 24, 2021
Bamlanivimab	Monoclonal Antibody	EUA – November 9, 2020 Revocation – April 16, 2021
Bamlanivimab & Etesevimab	Monoclonal Antibodies	EUA – February 9, 2021
Baricitnib (Olumiant)	Immune Modulator	EUA – November 19, 2020
Bebtelovimab	Monoclonal Antibody	EUA – February 11, 2022
Dexamethasone	Glucocorticoid	No EUA
Evusheld (tixagevimab & cilgavimab)	Monoclonal Antibodies	EUA – December 8, 2021
GOHIBIC (vilobelimab)	Monoclonal Antibody	EUA – April 4, 2023
Hydroxychloroquine & Chloroquine	Anti-inflammatory Treatments	EUA – March 28, 2020 Revocation – June 15, 2020
Kineret (anakinra)	Immune Modulator	EUA – November 8, 2022
Lagevrio (molnupiravir)	Antiviral	EUA – December 23, 2021
Paxlovid (Nirmatrelvir & Ritonavir)	Antiviral	EUA – December 22, 2021
Propofol-Lipuro 1%	Sedative	EUA – March 12, 2021
REGEN-COV (Casirivimab & Imdevimab)	Monoclonal Antibodies	EUA – November 21, 2020
Sotrovimab	Monoclonal Antibody	EUA – May 26, 2021 Paused due to Omicron variant – April 5, 2022
Veklury (Remdesivir)	Antiviral	EUA – May 1, 2020 Approved – October 22, 2020

Note. Adapted from "CDER scientific review documents supporting emergency use authorization for drug and biological therapeutic products: COVID-19" by the Food and Drug Administration, 2022b (https://www.fda.gov/drugs/coronavirus-covid-19-drugs/cder-scientific-review-documents-supporting-emergency-use-authorizations-drug-and-biological) and "Emergency use authorizations for drugs and non-vaccine biological products" by the Food and Drug Administration, 2023 (https://www.fda.gov/drugs/emergency-preparedness-drugs/emergency-use-authorizations-drugs-and-non-vaccine-biological-products).

Outpatient Medical Treatment

Individuals with mild illness generally do not require medical treatment and can often be managed at home through telemedicine (NIH, 2021c). Symptoms can be managed with over-the-counter medications, such as antipyretics, analgesics, and antitussives. Non-hospitalized individuals are advised to drink fluids to avoid dehydration. Other recommendations to aid minor dyspnea include resting in a prone position, as opposed to supine, and practicing breathing exercises (NIH, 2021d). No imaging or laboratory tests are indicated for patients with mild COVID-19. Older patients and those who are at higher risk for complications should be monitored more closely until they have recovered. Individuals with moderate COVID-19 have evidence of lower respiratory disease and should be monitored closely. Pulmonary disease has been shown to progress rapidly in patients with moderate illnesses. If secondary infections, such as pneumonia or sepsis, are suspected, the individual should be put on antibiotics (NIH, 2021c). Individuals not requiring hospitalization or supplemental oxygen, but who are at increased risk of severe disease progression, should be prescribed anti-SARS-CoV-2 monoclonal antibodies (mAb) or at-home antiviral medications. Other pharmaceutical treatments, such as

dexamethasone, are not recommended in this population without other indications for use (NIH, 2021d).

Hospitalized Treatment

Individuals who are hospitalized with COVID-19 infections may be treated with intravenous fluid administration, oxygen therapy, or corticosteroids or other pharmaceuticals (Nicola et al., 2020). Severe COVID-19 infections should be treated with supplemental oxygen therapy through a nasal cannula or high-flow oxygen device. Antibiotics should be prescribed to treat any secondary infections that may occur. Critically ill patients generally receive care in the intensive care unit (ICU). Successful management of a patient with critical illness includes treatment of COVID-19 and any other comorbidities or nosocomial complications that arise (NIH, 2021c). Individuals with moderate to critical illness may require non-invasive ventilation (NIV), such as continuous positive airway pressure (CPAP) or bilevel positive airway pressure (BiPAP), endotracheal ventilation, or invasive mechanical ventilation in order to reach the desired oxygen saturation level (NIH, 2021a; Nicola et al., 2020). Figure 5 summarizes therapeutic management options for hospitalized patients.

Figure 5

Therapeutic Management for Hospitalized Adults Based on Disease Severity as defined by the National Institute of Health last updated August 8, 2022

Disease Severity	Recommendations for Antiviral or Immunomodulator Therapy		Recommendations for Anticoagulant Therapy
	Clinical Scenario	Recommendation	
Hospitalized for Reasons Other Than COVID-19	Patients with mild to moderate COVID-19 who are at high risk of progressing to severe COVID-19[a]	See Therapeutic Management of Nonhospitalized Adults With COVID-19.	For patients without an indication for therapeutic anticoagulation: • **Prophylactic dose of heparin**, unless contraindicated **(AI)**; **(BIII)** for pregnant patients
Hospitalized but Does Not Require Oxygen Supplementation	All patients	The Panel **recommends against** the use of **dexamethasone (AIIa)** or **other systemic corticosteroids (AIII)** for the treatment of COVID-19.[b]	
	Patients who are at high risk of progressing to severe COVID-19[a]	**Remdesivir[c] (BIII)**	
Hospitalized and Requires Conventional Oxygen[d]	Patients who require minimal conventional oxygen	**Remdesivir[e] (BIIa)**	For nonpregnant patients with D-dimer levels above the ULN who do not have an increased bleeding risk: • **Therapeutic dose of heparin[g] (CIIa)** For other patients: • **Prophylactic dose of heparin**, unless contraindicated **(AI)**; **(BIII)** for pregnant patients
	Most patients	Use **dexamethasone plus remdesivir[e] (BIIa)**. If remdesivir cannot be obtained, use **dexamethasone (BI)**.	
	Patients who are receiving dexamethasone and who have rapidly increasing oxygen needs and systemic inflammation	Add **PO baricitinib[f]** or **IV tocilizumab[f]** to 1 of the options above **(BIIa)**.	

Figure 5, continued

Hospitalized and Requires HFNC Oxygen or NIV	Most patients	Promptly start 1 of the following, if not already initiated: • **Dexamethasone plus PO baricitinib[f] (AI)** • **Dexamethasone plus IV tocilizumab[f] (BIIa)** If **baricitinib, tofacitinib, tocilizumab,** or **sarilumab** cannot be obtained: • **Dexamethasone[h] (AI)** Add **remdesivir** to 1 of the options above in certain patients **(CIIa)**.[i]	For patients without an indication for therapeutic anticoagulation: • **Prophylactic dose of heparin**, unless contraindicated **(AI)**; **(BIII)** for pregnant patients For patients who are started on a therapeutic dose of heparin in a non-ICU setting and then transferred to the ICU, the Panel recommends switching to a **prophylactic dose of heparin**, unless there is another indication for therapeutic anticoagulation **(BIII)**.
Hospitalized and Requires MV or ECMO	Most patients	Promptly start 1 of the following, if not already initiated: • **Dexamethasone plus PO baricitinib[f] (BIIa)** • **Dexamethasone plus IV tocilizumab[f] (BIIa)** If **baricitinib, tofacitinib, tocilizumab**, or **sarilumab** cannot be obtained: • **Dexamethasone[h] (AI)**	

Note. From "Table 2b. Therapeutic management of hospitalized patients with COVID-19" by the National Institute of Health, 2022 (https://www.covid19treatmentguidelines.nih.gov/tables/therapeutic-management-of-hospitalized-adults/). In the public domain.

Long-Term Care Treatment

Individuals who have recovered from the COVID-19 infection itself, but who are experiencing post-acute COVID-19 syndrome or long-term health complications, should be monitored closely by a physician. Currently there is no consensus on the best way to manage this population. Patients may be monitored with at-home pulse oximetry, medications, or regular radiological or laboratory testing. Preliminary research suggests that corticosteroids may be an effective treatment for individuals with post-COVID inflammatory lung disease. Clinical trials are currently ongoing for the use of antifibrotic therapies for pulmonary fibrosis prevention following COVID-19 infection. Radiological measures and laboratory testing such as chest x-ray or CT, sputum sampling, echocardiogram, and pulmonary function tests, should be completed at regular intervals during recovery. For patients with severe pulmonary damage, lung transplants may be an option. Treatment varies depending on the severity of the COVID-19 illness, age of patient, comorbid conditions, whether or not a patient received ICU care, and what specific symptoms the individual is experiencing post-COVID-19 infection (Nalbandian et al., 2021).

Public Health Perspective

COVID-19 Community Levels

The Centers for Disease Control and Prevention (CDC) measures the levels of COVID-19 in communities in order to help health officials make decisions about community prevention strategies and to help individuals make informed decisions about their own health behaviors. COVID-19 community levels are classified as low, medium, or high based on the current cases and transmission rates. COVID-19 level alerts can serve as an early warning of a potential increase in COVID-19 cases that may put stress on the healthcare system. COVID-19 community levels can be determined for states, counties, or territories and are calculated based

on a few different metrics. The data used to calculate the community level are the number of new COVID-19 hospital admissions per 100,000 in the last seven days, the percentage of inpatient beds occupied by COVID-19 patients and staffed, and the total number of new COVID-19 cases in the last seven days per 100,000, as outlined in Table 4. The COVID-19 community level is determined using the higher of the inpatient beds occupied and new hospital admissions metrics, based on the number of new cases per 100,000 people in the last seven days (CDC, 2022a).

Table 4

COVID-19 Community Levels for the U.S. as last updated on March 24, 2022

	Fewer than 200 new COVID-19 cases per 100,000 people in the last 7 days			200 or more COVID-19 cases per 100,000 people in the last 7 days		
Community level	Low	Medium	High	Low	Medium	High
New COVID-19 hospital admissions per 100,000 people in the last 7 days?	<10.0	10.0 – 19.9	≥20.0	n/a	<10.0	≥10.0
Percent of staffed inpatient beds occupied by COVID-19 patients over a 7-day average	<10.0%	10.0% - 14.9%	≥15.0%	n/a	<10.0%	≥10.0%

Note. Adapted from "COVID-19 community levels" by the Centers for Disease Control and Prevention, 2022a (https://www.cdc.gov/coronavirus/2019-ncov/science/community-levels.html).

Prevention

Preventive measures such as education, isolation and quarantine, and controlling transmission are critical in keeping highly contagious diseases, like COVID-19, under control, especially in areas where transmission rates are high (Lofti et al., 2020). There are many personal preventive measures that individuals can take to reduce SARS-CoV-2 transmission, such as hand

cleaning, respiratory hygiene, ventilation, and disinfecting surfaces (McIntosh, 2021). The SARS-CoV-2 virus can survive on human skin for up to nine hours but is completely inactivated after being exposed to alcohol after fifteen seconds (Hirose et al., 2020). A hand sanitizer with at least 60% alcohol is recommended when diligent hand washing is not possible. Indoor spaces should be ventilated adequately by opening windows or doors, running heat or air conditioning fans, using fans to vent indoor air outside, or using a portable high-efficiency particulate air (HEPA) filter system (McIntosh, 2021).

Face masks can be an effective way to slow the spread of COVID-19 through source control and exposure prevention. Face masks help to contain secretions from individuals who may unknowingly be infected with SARS-CoV-2. Face masks may also help to prevent infection of the wearer if exposed to COVID-19. The World Health Organization recommends that facial coverings are worn in both indoor and outdoor settings where there is widespread COVID-19 transmission, in situations where social distancing is difficult or impossible, and in poorly ventilated indoor settings.. The Centers for Disease Control recommends that all unvaccinated individuals wear face masks any time they are around individuals who live outside of their immediate household. Either cloth or disposable masks or respirators, such as N95 masks, are recommended for use, as long as they fit snugly over the nose and mouth without gaps. Proper mask hygiene involves avoiding touching the face when putting on or taking off the mask, cleaning hands before and after touching the mask, and washing reusable cloth masks often (McIntosh, 2021). States may also mandate masks for specific business such as healthcare, long-term care facilities, and public transportation.

Social distancing is advised in locations where transmission of SARS-CoV-2 is at a medium or high community level. Social distancing involves maintaining a minimum distance

apart from other people outside of an individual's household. In the United States, the CDC recommends the minimum distance to be six feet, or two meters. In other areas of the world, the WHO suggests a minimum distance of three feet, or one meter. Social distancing is thought to reduce transmission of COVID-19, since close-contact with infected individuals is thought to be the primary risk of exposure to COVID-19 (McIntosh, 2021).

Other public health measures to try to reduce virus transmission include stay-at-home orders, nonessential business and school closures, public gathering bans, travel restrictions, contact tracing, and quarantine and isolation. These measures have been shown to reduce transmission and the incidence of COVID-19 infections. The guidelines and restrictions are revised as needed, depending on the incidence and transmission rates of the virus in different locations (McIntosh, 2021).

Individuals in locations with high COVID-19 community levels should take appropriate preventive measures. Additionally, individuals should be on the lookout for any symptoms that may arise and follow CDC guidelines for isolation and quarantine guidelines and testing recommendations (CDC, 2021a). CDC isolation and quarantine guideline changes over time are summarized in Table 5.

Table 5

COVID-19 Isolation and Quarantine Recommendations Over Time

Date	COVID-19 Exposure		Symptomatic/COVID-19 Positive	
	Vaccinated	Unvaccinated	Vaccinated	Unvaccinated
July 2020 - December 26, 2021	No need to quarantine unless symptoms begin. Take a COVID-19 test 3-5 days after exposure. Wear mask in public for 14 days	14-day quarantine May end quarantine if symptom free for 10 days, or after 7 days with a negative COVID-19 test within 48 hours of ending quarantine		
December 27, 2021 – present	No need to quarantine unless symptoms begin. Take a COVID-19 test 5 days after exposure. Wear mask in public for 10 days	5-day quarantine. Take a COVID-19 test on day 5. Wear a mask for 5 additional days.	Isolate for 5 days. Isolation can end when symptoms are resolving and the individual is fever-free. Wear a mask around others for 5 additional days.	

Note. Adapted from "CDC updates and shortens recommended isolation and quarantine period for general population" by the Centers for Disease Control and Prevention, 2021g (https://www.cdc.gov/media/releases/2021/s1227-isolation-quarantine-guidance.html) and "COVID-19: Epidemiology, virology, and prevention" by K. McIntosh, 2021, *UpToDate* https://www.uptodate.com/contents/covid-19-epidemiology-virology-and-prevention#H4014462337.

Vaccines

The development of a vaccine against COVID-19 had been a goal since the virus was first discovered. Previous research for vaccine development of SARS-CoV and MERS-CoV helped to expedite the vaccine development process for SARS-CoV-2 (Carr, 2021). The

development of vaccines involves preclinical evaluation and three clinical stages: phase I, II, and III trials. Phase I trials are designed to evaluate vaccine safety, immunogenicity, or the ability for cells to produce an immune response, and dosage. Phase II trials expand upon the safety and immunogenicity results from phase I, with a higher number of participants. Phase III trials determine vaccine efficacy, which is the reduction in disease incidence of those who received the vaccine and the control group. (Edwards & Orenstein, 2021). The World Health Organization has currently approved eleven vaccines against COVID-19, as shown in Table 6 (McGill COVID-19 Vaccine Tracker Team, 2022). In the United States, the FDA has approved the Pfizer/BioNTech, Moderna, Janssen (Johnson & Johnson), and Novavax vaccines for use (FDA 2021a, 2021b, 2022a, 2022f). As of August 2, 2022, a total of 12,308,330,588 vaccine doses have been administered worldwide (WHO, 2022b).

Table 6

COVID-19 Vaccines Granted Emergency Use Listing by WHO as of December 2, 2022.

Vaccine Name	Manufacturer	Type	Country Approval	Trials	Effective Date
Comirnaty	Pfizer/ BioNTech	RNA	149 countries, including the United States	100 trials in 31 countries	Dec 31, 2020
Vaxzevria	Oxford/ AstraZeneca	Non-Replicating Viral Vector	149 countries	73 trials in 34 countries	Feb 15, 2021
Covishield (Oxford/ AstraZeneca formulation)	Serum Institute of India	Non-Replicating Viral Vector	49 countries	6 trials in 1 country	Feb 15, 2021
Spikevax	Moderna	RNA	88 countries, including the United States	70 trials in 24 countries	April 30, 2021
Covilo	Sinopharm (Beijing)	Inactivated	93 countries	39 trials in 18 countries	May 7, 2021
Coronavac	Sinovac	Inactivated	56 countries	42 trials in 10 countries	June 1, 2021
Covaxin	Bharat Biotech	Inactivated	14 countries	16 trials in 2 countries	Nov 3, 2021
Jcovden Ad26.COV2.S	Janssen (Johnson & Johnson)	Non-Replicating Viral Vector	113 countries, including the United States	26 trials in 25 countries	Dec 3, 2021
Covovax (Novavax formulation)	Serum Institute of India	Protein Subunit	6 countries	7 trials in 3 countries	Dec 17, 2021
Nuvaxovid	Novavax	Protein Subunit	40 countries, including the United States	22 trials in 14 countries	Dec 20, 2021
Covidecia	CanSino	Non-Replicating Viral Vector	10 countries	14 trials in 6 countries	May 19, 2022

Note. Adapted from "11 vaccines approved for use by WHO" by the McGill COVID-19 Vaccine Tracker Team, 2022 (https://covid19.trackvaccines.org/agency/who/).

The currently approved COVID-19 vaccines are either RNA, non-replicating viral vector, inactivated, or subunit vaccines. RNA vaccines are also known as genetic material vaccines. These vaccines use a piece of messenger RNA (mRNA) that signals the body to create a protein that is present on the surface of the SARS-CoV-2 virus. The protein triggers the body's immune response to recognize and block the virus. This type of vaccine can generally be developed quicker than other vaccines and is thought to be safer for immunocompromised patients since it is not based on a live or weakened version of the virus. Inactivated vaccines are created from a component of the virus, which prompts an immune response, but no infection, in the body. This type of vaccine does not always elicit a strong immune response, and so multiple doses may be needed (Carr, 2021). Non-replicating viral vector vaccines contain a different, harmless virus that triggers the immune system to create spike proteins, which are found on the surface of the SARS-CoV-2 virus. This causes the body to recognize the protein as foreign and attack it when it comes in contact with the COVID-19 spike proteins (CDC, 2021d). Inactivated vaccines take the SARS-CoV-2 virus and inactivate, or kill, it using radiation, heat, or chemicals. This type of vaccine often requires multiple doses in order to achieve immunity over time (HHS, 2021; WHO, 2021). Subunit vaccines contain parts of a virus that best stimulate the immune system. The COVID-19 subunit vaccine contains harmless S proteins, that the immune system recognizes and subsequently creates antibodies to fight off the virus if it ever enters the body (Mayo Clinic Staff, 2022).

In the United States, the first vaccinations for COVID-19 began on December 14, 2020 (U.S. Department of Health and Human Services [HHS], 2022), when the Pfizer-BioNTech vaccine was given emergency use authorization by the FDA on December 11, 2020 (FDA, 2021b). The Moderna vaccine followed with emergency use authorization on December 18, 2020

(FDA, 2022a). The Janssen vaccine was later approved for emergency use on February 27, 2021 (FDA, 2021a). The Novavax COVID-19 vaccine was authorized for emergency use in adults who have not received a different COVID-19 vaccine on July 13, 2022 (FDA, 2022f). Vaccine distribution followed phase guidelines from the CDC. Phase 1a included healthcare personnel and residents of long-term care facilities. In phase 1b, vaccines were available to individuals aged 75 years or older, and frontline, non-health care, essential workers. Phase 1c made the vaccine available to individuals aged 65 to 74 years of age, individuals 16 to 64 with medical conditions that put them at high risk for the virus, and essential workers who were not eligible in the previous phase. Phase 2 of vaccine distribution expanded the eligibility criteria to all individuals older than 16 years of age who had not yet been eligible (Dooling et al., 2020). The Pfizer-BioNTech COVID-19 vaccine has been available for children aged 12 to 15 since May 10, 2021 (FDA, 2021b). On October 29, 2021, the FDA authorized the Pfizer-BioNTech COVID-19 vaccine for emergency use in children aged 5 to 11 years of age as well (FDA, 2021c). Additional COVID-19 vaccine doses became available to adults at least six months after completing the primary vaccination series (CDC, 2021f). The Pfizer and Moderna vaccines received full FDA approval on August 23, 2021, and January 31, 2022, respectively (FDA, 2021b, 2022a). As of March 5, 2022, the Janssen vaccine has been limited to use in individuals who can (or would) not receive the other vaccines. This limitation follows a pause in use from April 13, 2021, to April 23, 2021, due to thrombosis risk with thrombocytopenia syndrome (FDA, 2022e).

The COVID-19 vaccines help to alleviate disease burden by preventing infection, causing infected individuals to be less infectious, or preventing severe outcomes, such as

hospitalizations or death, in infected individuals (Caldwell et al., 2021). Vaccination is the most promising way to control the pandemic (Carr, 2021).

Auditory Effects of COVID-19

Despite preventive efforts, audiologists are evaluating and seeing patients in a clinical setting with auditory, vestibular, and tinnitus complaints. Hearing loss and other auditory effects following viral infection have been seen with many different illnesses (Saniasiaya, 2021), and there have been early reports of COVID-19 induced auditory or vestibular issues.

Asymptomatic COVID-19

Individuals who are asymptomatic, but test positive for COVID-19, may also experience auditory effects of the virus. Mustafa (2020) investigated the audiometric pure-tone hearing thresholds and transient evoked otoacoustic emission (TEOAE) amplitudes in 20 asymptomatic, COVID-19 positive individuals compared to a control group, who tested negative for COVID-19. Any participants with indications of a middle ear pathology from a tympanometry screening or a history of pre-existing hearing loss were excluded from this study. Participants were between the ages of 20 to 50 years of age, to exclude any potential age-related hearing impairments. Hearing sensitivity was normal in both groups; however, the high frequency thresholds were significantly worsened in the asymptomatic COVID-19 group. The COVID-19 group also had significantly reduced TEOAE amplitudes. This suggests that even asymptomatic COVID-19 infections can negatively affect the auditory system, but perhaps to a lesser degree.

Dror and colleagues (2020) investigated the auditory effects of recovered asymptomatic COVID-19 patients. Participants were categorized into two experimental groups: one group of recovered COVID-19 patients who had asymptomatic infections with no prior history of hearing impairment, and a control group of healthy, normal-hearing individuals matched for age and sex.

All participants were tested to obtain air conduction pure-tone hearing thresholds, tympanometry, TEOAEs, distortion product otoacoustic emissions (DPOAEs), and auditory brainstem response (ABR) results. There were no significant differences in TEOAE or DPOAE signal-to-noise ratios or amplitudes between the test and control groups. Pure-tone thresholds and ABR waveforms were normal in both groups as well. The results of this study indicate no differences in hearing sensitivity between the control group and asymptomatic COVID-19 recovered patients, suggesting that asymptomatic COVID-19 infections may not result in any measurable auditory damage.

Hearing Loss

Self-Reported Hearing Loss

In an early study, researchers found that eight individuals, or 5.8% of participants, self-reported a change in hearing following their COVID-19 diagnosis. Four of these individuals had a pre-existing hearing loss, which had reportedly worsened after COVID-19 infection. However, it is possible that an environmental change associated with hospital admission, or the use of face masks may have created difficult communication environments, leading to a recognition of a pre-existing hearing impairment (Munro et al., 2020).

Sensorineural Hearing Loss

Sensorineural hearing loss is often reported after COVID-19 infections, especially in the higher frequencies. Tan et al. (2022) compared the hearing thresholds for 26 COVID-19 positive and 27 COVID-19 negative individuals. Patients were included in the COVID-19 positive group if they were diagnosed with COVID-19 by PCR testing and had at least 30 days of illness. COVID-19 positive patients who had severe disease or were hospitalized in the ICU were not included in the study. The COVID-19 negative group consisted of 22 females and 5 males, with

a mean age of 23.96 ± 5.92. The COVID-19 positive group consisted of 14 females and 12 males, with a mean age of 34.20 ± 12.63. Patients who had any previously documented hearing or balance disorders, ear surgery, a history of occupational noise exposure, cardiovascular or circulatory problems, or were treated with chloroquine were excluded from this study. All participants underwent air conduction pure tone audiometry, TEOAEs, and a series of vestibular function tests (see page 59). No significant differences in TEOAE results were found between the COVID-19 positive and negative groups. There were no significant differences in air conduction hearing thresholds at 125-2000 Hz between those categorized as positive COVID-19 and those categorized as negative COVID-19. At 4000 Hz and 8000 Hz, significant differences existed between groups for both the right (4000 Hz p=0.001, 8000 Hz p=0.005) and left (4000 Hz p=0.001, 8000 Hz p=0.047) ears, suggesting that individuals affected by COVID-19 have poorer high frequency hearing thresholds than individuals who have not had COVID-19 (Tan et al., 2022).

Sudden Sensorineural Hearing Loss. A sudden-onset sensorineural hearing loss is a hearing loss of at least 30 dB present at a minimum of three consecutive frequencies that occurred within three days (Koumpa et al., 2020). There have been multiple case reports of sudden sensorineural hearing loss (SSNHL) following a COVID-19 infection. Koumpa and colleagues (2020) reported on a case where the patient was admitted to the hospital with severe COVID-19 symptoms and subsequently required intubation. He was treated with remdesivir and intravenous steroids, which helped to improve his COVID-19 condition. A week after being extubated, the patient reported tinnitus and a sudden onset of hearing loss on his left side, with no previous history of hearing loss or tinnitus. He was treated with intratympanic steroids, which helped to partially restore his hearing thresholds. It is unclear whether or not the COVID-19

infection was the cause of this sudden hearing loss, but since no other clear etiology was found, it seems plausible that there is an association.

A case of severe-to-profound bilateral sudden sensorineural hearing loss was reported in a 68-year-old woman after a high fever [unspecified] due to COVID-19 infection. Pre-COVID-19 diagnosis, this patient had a bilateral, cookie-bite configuration, mild, sensorineural hearing loss. The patient reported intense bilateral tinnitus the day prior to developing a noticeable sudden change in hearing. The initial audiogram after the sudden hearing loss revealed a profound low-frequency hearing loss rising to severe sensorineural hearing loss in the right ear and no pure-tone responses at any test frequency in the left ear. The patient was treated with multiple rounds of oral steroids and intratympanic steroid injections. The final audiogram after treatment improved to a severe-profound sensorineural hearing loss bilaterally. This patient is thought to be the first reported case of bilateral SSNHL related to COVID-19 (Edwards et al., 2021).

Ricciardiello and colleagues (2021) compiled five case reports of sudden sensorineural hearing loss in individuals with mild COVID-19 infections. In addition to unilateral sudden sensorineural hearing loss, some patients also reported sudden onset tinnitus and vestibular symptoms. As soon as the patients no longer tested positive for SARS-CoV-2 on RT-PCR tests, they underwent complete audiological and vestibular assessments and promptly began the appropriate medical treatments. Patients were treated with a combination of high dose oral steroids, mesoglycan, and hyperbaric oxygen therapy. After treatment, the degree of improvement in hearing thresholds varied from slight to full recovery. These five case reports suggest that SSNHL and other audiological and vestibular symptoms may be occasional symptoms, even in mild COVID-19 cases.

It has been hypothesized that sudden sensorineural hearing loss could be the sole presenting symptom in an otherwise asymptomatic COVID-19 infection. Kilic and colleagues (2020) investigated the presence of a SARS-CoV-2 infection in individuals who came into an otolaryngology clinic with reports of a unilateral sudden-onset hearing loss. Five patients presented with unilateral SSNHL between April 3, 2020, and April 10, 2020. After audiologic evaluation, these individuals were referred for RT-PCR COVID-19 testing. One of the five patients had a positive COVID-19 test result. In this case, it is possible that non-specific symptoms, such as SSNHL, could be the only sign of an active COVID-19 infection. However, this is a singular case report, and it is also possible that the COVID-19 infection and the SSNHL were merely coincidental.

Conductive or Mixed Hearing Loss

Conductive or mixed hearing losses are less commonly reported than sensorineural hearing loss in COVID-19 patients. If reported, these cases are usually accompanied with otitis media and otalgia. It is possible that in these instances, the hearing loss is not due to COVID-19 itself, but due to normal life circumstances and unrelated, coinciding otitis media with an active COVID-19 infection (Almufarrij & Munro, 2021),

Fidan (2020) describes a case of a 35-year-old woman who presented with otalgia and tinnitus, without any typical COVID-19 symptoms. The patient underwent air and bone conduction pure tone audiometry and tympanometry testing. In addition to a chest x-ray, a RT-PCR SARS-CoV-2 test was also obtained out of an abundance of caution, since this patient was evaluated in the early stages of the pandemic. Her chest x-ray revealed bilateral lung involvement, and her RT-PCR test came back positive for COVID-19. Pure tone testing revealed

a conductive hearing loss with a Jerger Type B tympanogram in her right ear with normal hearing sensitivity in the left ear. Tympanometry results for the left ear were not reported.

Since there appeared to be an association between COVID-19 infection and otitis media, Raad et al., (2020) investigated COVID-19 patients who had reported otologic symptoms, such as otalgia, otorrhea, or hearing loss. Eight out of 19 of the COVID-19 patients had middle ear effusion, three had acute otitis media, and one had a tympanic membrane perforation, resulting in hearing loss. Patient 1 was a 38-year-old male who presented to the ENT clinic with chronic cough, mild dyspnea, anosmia, hearing loss, and aural fullness/pressure in his ears. Otoscopy revealed bulging tympanic membranes with purulent effusion. He tested positive for COVID-19 on a PCR test. All of the symptoms, except for anosmia, resolved within two weeks. Patient 2 was a 35-year-old female who tested positive for COVID-19 with a PCR test with sudden onset anosmia, and coarse crackles of the upper lobe of her left lung. The patient had no complaints of otologic symptoms, however, otoscopy revealed bilateral middle ear effusion. Patient 3 was another 25-year-old female who had a positive PCR COVID-19 test was admitted due to cough and progressive dyspnea. After admission, the patient developed unilateral otalgia and hearing loss. A unilateral red tympanic membrane was evident on otoscopy. The hearing loss and otalgia gradually improved over the course of a few days. Patient 4, a 20-year-old female, presented to the ENT clinic with left ear otalgia and hearing loss, without any COVID-19 symptoms. Otoscopy revealed left ear effusion, and severe tympanic membrane bulging. This patient had recently been exposed to the virus, but her RT-PCR oropharyngeal test had come back negative. The patient had a myringotomy to drain middle ear fluid to relieve the pressure and otalgia. A PCR test was completed on fluid from her middle ear, which tested positive for SARS-CoV-2. The patient never developed COVID-19 symptoms, and her hearing loss [unspecified type]

resolved in a few weeks. Patient 5, a 22-year-old female, tested positive for COVID-19 on a nasopharyngeal PCR test. The patient reported cough, left sided otalgia, aural fullness, hearing loss, and “ear popping.” Otoscopy revealed reduced mobility of the left tympanic membrane, with evidence of bulging, hypervascularity, and purulent middle ear effusion. Pure tone air and bone conduction testing revealed a 15 dB conductive hearing loss with a mild sensorineural hearing loss at the higher frequencies in the left ear. Testing of the right ear revealed normal hearing sensitivity. Patient 6, a 25-year-old female, also presented with unilateral hearing loss, but in the right ear. The patient was also experiencing cough and had coarse and fine crackles and ground glass opacifications in the right lung. She tested positive for COVID-19 on PCR tests, and all symptoms resolved within one month. Patients 7, a 22-year-old female, and 8, a 45-year-old female, both tested positive for COVID-19 with a PCR test and reported unilateral otalgia and hearing loss. Patient 7 had evidence of otitis media with effusion on otoscopy and tympanometry. Her symptoms were fully resolved within 30 days. Otoscopy of patient 8 revealed a central tympanic membrane perforation with purulent otorrhea. With treatment, her symptoms resolved within a week and the perforation had fully healed at her six-week follow-up.

Tinnitus

Tinnitus is a symptom that can have detrimental effects on an individual’s quality of life. The COVID-19 pandemic may exacerbate the negative effects of tinnitus (Narozny et al., 2021), and there have been reports of new or increased tinnitus in recovered COVID-19 patients (Daher et al., 2022; Munro et al., 2020; Viola et al., 2021; Xia et al., 2021).

From a survey of 185 hospitalized COVID-19 patients by Viola et al., (2021), 43 patients (23.2%) reported experiencing tinnitus after receiving their diagnosis. Of these, 39.4% described their tinnitus as recurrent, 23.3% described it as episodic or sporadic, 16.3% described it as

continuous with changes in intensity throughout the day, 13.9% described it as persistent or continuous, and 7% experienced pulsatile tinnitus. This suggests that there may be an association between COVID-19 infections and tinnitus, however it is unclear whether any of these participants had tinnitus prior to their COVID-19 diagnosis as well (Viola et al., 2021).

Munro et al. (2020) surveyed 138 adults eight weeks after admission to the hospital due to severe COVID-19 symptoms. Of the 13.2% (n=16) of patients who reported changes in hearing or tinnitus after being diagnosed with COVID-19, eight patients (5.8% of the total group surveyed) reported new or worsened tinnitus specifically. Three of these patients had pre-existing hearing loss. There were no reports of hearing and tinnitus changes in this same patient. Munro et al. suggest that it is possible that the environmental changes associated with hospital admission and the use of face masks may have resulted in patient perceptions of pre-existing tinnitus or worsening tinnitus. It is also possible that the increased anxiety that coincides with COVID-19 may have contributed to the perception of worsening tinnitus, since tinnitus and anxiety are highly related.

COVID-19 associated anxiety levels in tinnitus patients were evaluated in a study by Xia and colleagues (2021). The goal of this study was to investigate whether or not anxiety levels were increased by the COVID-19 pandemic in patients with tinnitus, and if the increased anxiety also increased the tinnitus severity and the outcomes of tinnitus treatments. The researchers compared anxiety levels and tinnitus treatment outcomes among patients in 2020 experiencing COVID-19 pandemic related stress and anxiety (n=89) and patients in the matching period in 2019 (n=99). Both groups completed Zung's Self-rating Anxiety Scale (SAS), Tinnitus Handicap Inventory (THI), and a test of tinnitus loudness (TL). These assessments were administered before any intervention and then repeated after sound therapy and/or educational counseling

intervention. Data was analyzed using t-tests, analysis of variance (ANOVA), and chi-square tests. There was a significant increase in anxiety levels in individuals with tinnitus as measured with the SAS in patients from the 2020 group compared to the 2019 group ($p=0.026$), suggesting an increase in anxiety levels in tinnitus patients due to the COVID-19 pandemic. The THI scores were significantly higher in the 2020 group as well ($p < 0.001$), suggesting that the increase in anxiety also manifested as an increase in tinnitus symptoms. Interestingly, the THI score for the non-anxiety subjects in 2020 was the same as the THI score for the anxiety group in 2019. In response to treatment with sound therapy, educational counseling, or both, tinnitus in the 2019 group was improved, as shown by decreases in the tinnitus handicap inventory (THI) score and tinnitus loudness measures. Educational counseling alone also resulted in improved tinnitus in the 2019 group, as measured by the THI and TL test. However, in the 2020 group, THI scores and tinnitus loudness severity continued to increase, despite educational counseling intervention. Based on these results, researchers concluded that the COVID-19 pandemic increased stress and anxiety levels in tinnitus patients, resulting in increased tinnitus handicap and tinnitus loudness, which may be less sensitive to traditional tinnitus treatments.

Daher and colleagues (2022) report on a case of a 49-year-old male who developed bothersome tinnitus shortly after recovering from a mild COVID-19 infection. The tinnitus was bilateral, constant, and non-pulsatile in nature. This individual had normal hearing sensitivity and reported no other auditory issues. Treatment with white noise masking and gabapentin, an anticonvulsive agent thought to increase gamma-aminobutyric acid (GABA) in the central nervous system, as a potential treatment for tinnitus (Tavares & Bahmad, 2022), was effective in reducing the tinnitus symptoms in this patient. While the patient still reported having tinnitus, it had been reduced to an acceptable level after two weeks on the medication. The researchers

hypothesized that this patient's experience may represent a small group of COVID-19 patients who experience new-onset tinnitus, while their hearing remained normal.

Vestibular Effects of Covid-19

Dizziness or vertigo have been reported as one of the main clinical manifestations of COVID-19 infections in many patients. Dizziness itself is a non-specific symptom of COVID-19, but it should not be dismissed or taken lightly, as it has been shown to be a notable clinical manifestation of the virus (Abdelrahman & Shafik, 2021). In a comprehensive literature review by Saniasiaya and Kulasegarah (2021), 141 patients who experienced dizziness and/or vertigo associated with COVID-19 were identified. In three patients, dizziness was the initial symptom of the infection, and two of these patients later developed respiratory symptoms. Viola and colleagues (2021) surveyed hospitalized COVID-19 patients (n=185) and found that 18.4% (n=34) reported balance disorders, either dizziness (94.1%, n=32) or acute vertigo attacks (5.9%, n=2). In addition to dizziness, COVID-19 patients have reported other vestibular issues, including nystagmus, benign paroxysmal positional vertigo, and vestibular neuritis.

Asymptomatic COVID-19

Individuals who test positive for COVID-19 on a PCR test, but remain asymptomatic, may have damage to their vestibular systems that is attributed to the viral infection. Mustafa and Taya (2020) investigated possible vestibular effects of asymptomatic COVID-19 infections by comparing the latencies of vestibular evoked myogenic potentials (VEMPs) of asymptomatic COVID-19 cases and normal, COVID-19 negative individuals. The experimental group consisted of 20 individuals who were confirmed positive for a COVID-19 infection but had no symptoms. Participants were between the ages of 20 and 50. Any participants who had a known history of hearing loss or vestibular dysfunction were excluded from the experimental group.

Twenty normal hearing individuals with hearing thresholds at or better than 15 dB HL with no history of a known cause of hearing loss were used as the control group. All participants underwent a full case history and ENT examination, basic audiometric evaluations, tympanometry, and vestibular evoked myogenic potentials. Paired t-tests were used to compare test results between groups. No significant difference in hearing sensitivity was found between groups ($p > 0.05$) at all frequencies tested except for 4000, 6000, and 8000 Hz, where a significant difference was found ($p < 0.05$). All participants had middle ear pressure and compliance within normal limits, as measured by tympanometry. There was a highly significant difference in VEMP latencies between the asymptomatic COVID-19 positive group and the control group ($p < 0.001$), indicative of damage to the saccular vestibular hair cells. This suggests that even asymptomatic COVID-19 infections can cause physiological damage to the vestibular system.

Dizziness and Nystagmus

Nystagmus is defined as the repetitive, uncontrolled eye movements, alternating between fast and slow movements. These involuntary eye movements can be congenital or acquired and may be spontaneous or triggered by certain head maneuvers. It is possible to identify the location of the vestibular lesion and cause of the nystagmus based on the characteristics of the eye movements. Viral infections, such as Zika virus and human immunodeficiency virus (HIV), have been known to be a potential cause of nystagmus, including the virus that causes COVID-19 (García-Romo et al., 2021).

In one instance, a young woman initially presented to a primary care physician with cough, rhinorrhea, fever, headache, and anosmia. Three weeks later, she began experiencing episodes of dizziness with nystagmus several times a day. Emergent examination by an

ophthalmologist revealed horizontal asymmetrical gaze nystagmus with a duration of about 10 seconds in both eyes, but slightly worse in the left eye. This patient underwent radiologic, audiologic, and vestibular testing and all test results were normal. Four months after the onset of her symptoms, the patient reported a gradual improvement in symptoms, with "one or less episodes of nystagmus per day." This patient was not tested for COVID-19 at the time of her initial symptoms, but later underwent serological measures to test for COVID-19 IgG antibodies, which came back positive. This suggests that this individual had been infected with SARS-CoV-2, likely explaining her initial symptoms. Since this patient had no other significant history or abnormal test results, it is possible that the nystagmus was due to COVID-19. This may be a manifestation of acute cerebrovascular disease or direct central nervous system involvement associated with SARS-CoV-2 (García-Romo et al., 2021).

Abdelrahman and Shafik (2021) completed videonystagmography (VNG) testing on 20 post-COVID-19 patients who were complaining of persistent dizziness. Patients were classified by illness severity, as defined by NIH criteria (NIH, 2021c), and underwent oculomotor tests, including random saccade, smooth pursuit, optokinetic, and gaze testing, spontaneous nystagmus, positioning, positional, and caloric tests. Seventy percent of participants had abnormal VNG findings on the positioning, positional, and caloric tests, mostly indicating positional nystagmus (65%) and unilateral caloric weakness (40%). Twenty percent of patients had spontaneous nystagmus. Asymmetrical caloric responses were found in 25-33.33% of COVID-19 subjects regardless of the degree of COVID-19 severity (mild, moderate, or severe) as defined by NIH (2021c). These authors concluded that COVID-19 can have a significant effect on COVID-19 can cause a significant effect on VNG test results.

In addition to the pure tone audiometry and TEOAE tests (as described on page 39), Tan et al. (2022) investigated the effect of COVID-19 infection on vestibular function in recovered COVID-19 patients compared to a control group. The vestibular test battery was made up of bedside vestibular screenings, the European Evaluation of Vertigo scale (EEV), video head impulse test (vHIT), cervical and ocular VEMP, and videonystagmography (VNG). Recovered COVID-19 patients had an average score of 4.5 on the EEV, which was significantly different from the control group ($p<0.05$). The recovered COVID-19 group also had significant correlation between the normal and pathological values on the tandem Romberg ($p=0.006$), Fukada ($p=0.035$), and tandem gait ($p=0.006$) bedside screening tests. On the VNG test battery, no pathological results were found in either group on the gaze vertical or horizontal, pursuit, dix Hallpike, or head roll tests. However, there were significant differences between the COVID-19 recovered and control groups ($p=0.001$) on the head shake test. vHIT results indicated significant differences in gain asymmetry measurements for the vHIT LARP ($p=0.041$) and vHIT RALP ($p=0.003$). Both oVEMP and cVEMP results were found to differ between groups in terms of P1/N1 latency measurements and amplitude measurements in one ear, resulting in abnormal amplitude asymmetry ratios ($p=0.002$ for cVEMP and $p=0.004$ for oVEMP). The results of this study show that the vestibular system may be affected in individuals who have recovered from COVID-19.

Benign Paroxysmal Positional Vertigo

Benign paroxysmal positional vertigo, or BPPV, is a peripheral vestibular pathology in which patients experience rotational vertigo or an abnormal sense of motion after changing position of their head, generally lasting less than a minute. BPPV can be due to cupulothiasis or canalithiasis. Cupulothiasis occurs when displaced otoconia attach to the cupula in one of the

semicircular canals (Schuknecht, 1969). Canalithiasis occurs when the displaced otoconia float freely in one of the semicircular canals (Epley, 1992). BPPV can develop from many causes, including traumatic brain injury, Meniere's Disease, vestibular neuritis, and infection, or it may be idiopathic in nature (Picciotti et al., 2021).

There have been a few reports of patients who have been affected by BPPV due to COVID-19 infection. The medical records of eight patients with COVID-19 infections and vertigo, without audiological symptoms, were reviewed by Picciotti et al., (2021). The patients had COVID-19 infections, with mild to critical symptoms. None of the patients had a history of vertigo or other vestibular issues prior to their COVID-19 infection. Using video-oculography and Frenzel glasses, all eight patients were noted to have spontaneous, positional, and positioning nystagmus and were further investigated to confirm the diagnosis of BPPV. Individuals with BPPV due to cupulothiasis that involved the posterior semicircular canal showed torsional upbeat nystagmus during the Dix-Hallpike and Semont maneuvers. Individuals with BPPV due to canalithiasis involving the horizontal semicircular canal displayed horizontal nystagmus towards the upper or lower ear when in a supine position and their head was turned rapidly from side to side. All patients were successfully treated with various repositioning maneuvers, until the vertigo and nystagmus resolved (Picciotti et al., 2021).

Vestibular Neuritis

Vestibular neuritis is also known as acute unilateral peripheral vestibulopathy, which is an acute vestibular disorder involving sudden-onset vertigo, nausea, vomiting, unsteady gait, spontaneous nystagmus, and head-motion intolerance. Vestibular neuritis can be diagnosed by confirming the presence of a unilateral peripheral vestibular impairment on caloric tests or vHIT

(Mat et al., 2021). There have been multiple reports of COVID-19 induced vestibular neuritis, often as the presenting symptom of the virus.

A thirteen-year-old female presented with sudden-onset rotary vertigo and vomiting, with no other reported symptoms (Mat et al., 2021). Physical examination revealed a grade three spontaneous horizonto-rotary nystagmus on the right side and a deviation to the left on the Fukuda stepping test. Head impulse testing was positive on the left side and vHIT revealed abnormalities for the left anterior and lateral semicircular canals, suggestive of vestibular neuritis. Once this diagnosis was confirmed, she began vestibular rehabilitation. At this time, the patient was tested for COVID-19 after a family member became ill. Her PCR test was positive, and she was sent home to isolate and continue vestibular rehabilitation at home. It is hypothesized that in this case, vestibular neuritis was the sole presentation of a COVID-19 infection.

A similar case where vestibular neuritis was a presenting symptom of COVID-19 occurred in a 29-year-old female (Malayala & Raza, 2020). This patient presented with sudden onset severe vertigo, nausea, and vomiting. No other symptoms were present at this time. CT scans were taken of her head and chest/abdomen to rule out pathology. The chest CT revealed bilateral ground-glass opacifications, which are commonly seen with COVID-19 pneumonia. A COVID-19 PCR test was administered and came back positive. The patient was treated with hydroxychloroquine and azithromycin, based on the treatment recommendations in March 2020. This treatment minimally improved her vestibular symptoms, and vestibular rehabilitation was started. Her symptoms gradually improved with vestibular rehabilitation. The patient recovered from her COVID-19 infection after eight days in the hospital and seven more days quarantining at home.

Auditory Processing Effects of COVID-19

COVID-19 survivors often experience “brain fog”, which has been described as a mild cognitive impairment. The symptoms that many patients experience with post COVID-19 brain fog are similar to those seen in patients with an auditory processing disorder. DiSogra (2022) hypothesizes that COVID-19 brain fog and auditory processing disorder (APD) may be related. Symptoms that overlap with COVID-19 brain fog and APD include delays responding to oral communication, difficulty attending or staying focused, and word finding problems.

It is possible that even mild COVID-19 infection can result in changes in the brain. In a study of brain scans and cognitive tests, researchers studied 401 volunteers who had been infected with COVID-19 between March 2020 and April 2021 compared to an age and sex matched control group of 384 volunteers who had never had COVID-19. The group with a positive history of COVID-19 had greater loss of gray matter thickness and tissue damage in areas of the brain associated with the sense of smell, decreased whole-brain volume, increased cerebrospinal fluid volume, and a decline in ability to perform complex tasks. Other brain structures affected included the cingulate cortex, amygdala, hippocampus, and limbic cortical areas, which have a role in auditory processing (Abbasi, 2022; Douaud et al., 2021). Researchers did not explicitly investigate auditory processing, but neurological damage is a known risk factor and potential cause for an auditory processing disorder (ASHA, n.d.-b), and it is possible that the changes in brain structure may contribute to auditory processing difficulties.

In a study by Boboshko et al. (2022), researchers assessed the impact of COVID-19 on hearing function in adults. Participants were included in this study if they were over the age of 18, had complaints of hearing impairment and/or tinnitus during or after having COVID-19, and had recovered from COVID-19 infection no earlier than 2 weeks and no later than 24 weeks

before the audiological check. Participants were excluded if they were younger than the age of 18, if they did not have any hearing complaints, or if they had a comorbid condition such as a severe somatic and neurological pathology. One hundred and sixty-one individuals were included in this study (120 women and 41 men, mean age 60 ± 13.1 years). Participants underwent air and bone conduction pure tone testing, tympanometry, ipsilateral acoustic reflex thresholds, and speech recognition testing, and a central auditory processing assessment. The auditory processing assessment included the Random Gap Detection Test, the maximum speech recognition score of monosyllabic words in quiet and noise tests, dichotic digits test, Binaural Fusion Test, and the Russian matrix sentence test in quiet and noise. 24% (n=39) of the participants were found to have normal hearing sensitivity, and 76% (n=122) had a unilateral or bilateral hearing loss. On the Random Gap Detection Test, only 59% of normal hearing participants and 17% of participants with hearing loss were able to complete the task successfully. While speech testing in quiet is not an auditory processing disorder detection test, 33% of participants scored 60% or poorer on the monosyllabic words in quiet test, which may explain why so many participants performed poorly on other auditory processing tests. Poor monosyllabic words in noise scores were evident in 42% of patients. Binaural fusion and dichotic digits tests were only performed in 24 listeners, which revealed scores of 68% ± 34% on the binaural fusion test and poor scores in 54% of patients on dichotic digits. On the Russian Matrix test, poorer results were correlated with the duration and severity of COVID-19 infection, suggesting a direct influence on the virus on the auditory cortex. The researchers in this study concluded that decreased speech test results in patients after recovering from COVID-19 infection may be a sign of an auditory processing disorder, but more investigation is needed, especially since hearing loss is a contraindication to many auditory processing tests.

Auditory and Vestibular Pathophysiology of COVID-19

It is challenging to determine the underlying pathophysiology of the auditory and vestibular effects of COVID-19 due to the inaccessibility of the cochlea to histopathological examination in living persons. The exact underlying mechanisms regarding how SARS-CoV-2 can affect the auditory and vestibular systems is unknown, but many theories exist. The auditory and vestibular pathophysiology of COVID-19 infection may be due to a variety of different mechanisms, including inflammation of the cochlear nerve, cochlear or perilymphatic tissue inflammation, cross-reactions between antigens in the inner ear and SARS-CoV-2, or indirect viral transmission from cerebrospinal fluid to the inner ear. Other potential mechanisms include hematogenic transmission, ischemia, ototoxicity, prolonged hospitalization, peripheral neuropathies, and nasopharyngeal infection (Saniasiaya, 2021).

Hematogenic Transmission

The sensorineural hearing loss that sometimes occurs with SARS-CoV-2 may be the result of direct infection into the cochlea and/or inflammation leading to cell stress (Koumpa et al., 2020). The SARS-CoV-2 virus attaches itself to hemoglobin and gains entry to the erythrocytes, or red blood cells, which allows it to infect other tissues by binding to its surface receptor: angiotensin-converting enzyme 2 (ACE2). ACE2 is abundant in the brain, medulla oblongata, and temporal lobe. As the ACE2 receptors in these structures become infected, the part of the brain responsible for hearing is also infected, leading to potential complications, such as hearing loss. When the virus binds to the ACE2 receptors, cytokines, such as tumor necrosis factor-α, interleukin 1, and interleukin 6, are released. This triggers an immune response of inflammation, which can cause cellular damage due to stress (Koumpa et al., 2020; Saniasiaya,

2021). The red blood cells are deoxygenated as SARS-CoV-2 binds to them, potentially leading to hypoxia of the hearing centers in the brain, and permanent hearing loss (Saniasiaya, 2021).

Ischemia

Another possible mechanism of SARS-CoV-2 effects on the auditory and vestibular systems is vascular damage due to ischemia. Any vascular damage can cause damage, since the inner ear is very sensitive to ischemia (Tan et al., 2022). ACE2 is also found in vascular smooth muscle, and when it becomes infected, blood clots may form. These blood clots diminish the blood supply and cause ischemia, which may lead to hearing loss if the ischemia is severe enough and affects the hearing-related brain structures. It is thought that the elderly population are most susceptible to COVID-19 induced hearing loss by this mechanism (Saniasiaya, 2021). Vasculitis, or inflammation of blood vessels, can lead to decreased blood and oxygen flow. Vasculitis may occur in COVID-19 patients and is known to cause audio-vestibular damage when the central nervous system is directly affected (Viola et al., 2021).

Ototoxicity

It is possible that the pharmaceuticals that are being used to treat COVID-19 infections may be causing auditory damage, due to ototoxicity. Chloroquine (CQ) and hydroxychloroquine (HCQ) are medications that were commonly used in the early months of the pandemic to treat COVID-19 infections. Both medications are known to be ototoxic, and have been reported to cause sensorineural hearing loss, tinnitus, and balance deficits. While these medications are not currently used for routine COVID-19 treatment, it is possible that some of the early reports of COVID-19 induced auditory/vestibular dysfunction may be attributed to these medications (De Luca et al., 2021).

Prolonged Hospitalization

It has been hypothesized that hospitalization and admission into the intensive care unit (ICU) may create an environment in which vestibular dysfunction may occur. Prolonged bed rest and immobilization while in the ICU may lead to the development of BPPV in COVID-19 patients. Many COVID-19 patients are placed in a prone position while in the hospital for better oxygenation, and prolonged time spent in this position may also lead to the development of positional vertigo, especially involving the horizontal semicircular canal (Picciotti et al., 2021).

Peripheral Neuropathies

There have been reports linking COVID-19 with a variety of peripheral neuropathies, such as Guillian-Barre syndrome (GBS). Given the risk of impairment of the auditory pathway with many peripheral neuropathies, it is possible that auditory dysfunction in this population may be more related to the peripheral pathology. Auditory neuropathy spectrum disorder has been linked to some peripheral neuropathies, including GBS, and so permanent hearing loss in response to COVID-19 infection in this population may be part of the immune-mediated complex (Saniasiaya, 2021).

Nasopharyngeal Infection

Many viruses, including COVID-19, that cause upper respiratory infections can induce acute otitis media (Raad et al., 2020). When the nasopharynx is infected, the infection can ascend in the system, leading to middle ear effusion. This may explain the conductive hearing loss that is sometimes seen with COVID-19 patients (Saniasiaya, 2021). Viral infections can reduce the clearance of mucosal cells in the nasopharynx and eustachian tube, which can lead to negative middle ear pressure, predisposing the middle ear to effusion and infection. ACE2 receptors are highly concentrated in the nasal respiratory tract and inferior portion of the Eustachian tube.

Since SARS-CoV-2 enters cells via these receptors, upper respiratory infection may be a potential route for SARS-CoV-2 to infect the middle ear (Raad et al., 2020).

Summary

Coronavirus Disease 2019 has infected many people, and many more are likely to be infected, or reinfected, in the years to come. With increasing numbers of infected individuals, more reports of auditory and vestibular effects are expected. Audiologists need to be aware of the audiological complications that can arise from a COVID-19 infection and should be prepared to evaluate and provide non-medical treatment to this unique population.

CHAPTER II

APPLICATION TO AUDIOLOGY

COVID-19 as an Occupational Health Hazard for Audiologists

The risk of worker exposure to COVID-19 depends on many factors, including work environment, community transmission rates, existing medical conditions of workers, and measures available to control disease impact. The Occupational Safety and Health Administration (OSHA) has divided jobs into four different exposure risk levels: low risk (caution), medium risk, high risk, and very high risk. Jobs that do not require close contact with other individuals, like remote workers, telemedicine healthcare providers, or office workers with limited contact with others, are considered part of the lower risk, or caution, groups. The medium risk group includes occupations such as those who have frequent contact with coworkers or the general public in well-ventilated spaces or those who live in shared housing facilities or temporary labor camps, especially in areas with high community transmission. High exposure risk jobs are those with a high potential for exposure to suspected or known sources of COVID-19. These jobs include healthcare workers who must enter COVID-19 patient rooms, medical transport workers, mortuary workers, and those who have close contact with coworkers or the general public in poorly ventilated spaces. Workers who are likely to come in contact with SARS-CoV-2 during medical, postmortem, or laboratory procedures are at very high exposure risk. This may include healthcare workers performing procedures that generate aerosol, such as intubation, bronchoscopies, a few dental procedures, or specimen collection on COVID-19

patients. This may also include laboratory workers handling COVID-19 specimens, or morgue workers performing autopsies on COVID-19 patients (OSHA, n.d.).

OSHA requires employers to create a work environment that is free from hazards that may cause death or serious physical harm (OSHA, 1970). Employers may be required to provide personal protective equipment (PPE) or respiratory protection to workers. Employers should take necessary precautions if workers could be exposed to hazardous environments or materials that could be contaminated with SARS-CoV-2. Employers should also ensure that infected or exposed individuals are identified and appropriate control measures, such as self-monitoring quarantine periods, are implemented (OSHA, n.d.).

Under the Americans with Disabilities Act (ADA) (1990), individuals who are experiencing post-acute COVID-19 syndrome may be entitled to workplace accommodations. These accommodations may include providing or modifying equipment or devices, modified work schedules, reassignment to a vacant position, or adjusting examinations, policies, or training materials (Batiste, 2021; Biden-Harris Administration, 2021).

COVID-19 in Healthcare Settings

Depending on the specific healthcare setting, guidelines and requirements for employers/providers may vary. The Colorado Department of Public Health and Environment (2021) breaks down healthcare workers into three groups: health care facilities, long-term and residential care facilities, and limited health care facilities. Limited health care facilities are those offering services such as audiology, speech-language pathology, occupational therapy, and chiropractic care. COVID-19 is rapidly evolving, and audiologists and other health care workers should keep up to date with state and national agencies, such as the Department of Regulatory Agencies (DORA; https://dora.colorado.gov/covid-19-updates-for-licensees-consumers), the

Colorado Department of Public Health and Environment (https://covid19.colorado.gov/), and the Centers for Disease Control and Prevention (https://www.cdc.gov/coronavirus/2019-ncov/index.html).

Reducing Risks in Audiology

Clinical recommendations for reducing the risk of COVID-19 transmission for audiologists may vary as a function of work setting. Both the American Academy of Audiology (AAA) and the American Speech-Language Hearing Association (ASHA) offer COVID-19 resources and guidelines for audiologists (AAA, n.d.; ASHA, n.d.-a). For audiologists working in a larger health care system, the recommendations will likely come directly from the health system. For audiologists working in private practices or smaller clinics, the recommendations may be less clear. In these scenarios, audiologists should monitor the CDC and other local governing bodies for specific recommendations (AAA, n.d.) and develop their own practice policies. In all settings where community transmission exists, COVID-19 infection control protocols should be put in place. These protocols may include screening for potentially infected individuals, face masks, limiting visitors, vaccination, and disinfection of the environment.

To identify potentially infected individuals, a health screening should be conducted on all individuals prior to entering a healthcare facility, which can be done on-site, online, or over the phone. This screening should rule out the presence of common COVID-19 symptoms, such as cough, shortness of breath, fatigue, sore throat, and headache. A temperature check should be conducted prior to entry as well, to rule out the presence of fever. Larger healthcare facilities may require proof of vaccination and/or a negative COVID-19 PCR test prior to admission into the facility. Until recently, the use of face masks in most healthcare settings was required for all patients, visitors, and staff, as this helps to prevent transmission of SARS-CoV-2 (Palmore &

Smith, 2022). UCHealth systems lifted their mask mandate in hospitals and clinics on March 1, 2023, and Mayo Clinic lifted their face mask requirements on April 10, 2023 (Jacobson, 2023; McCrimmon, 2023).

During times of high community transmission of COVID-19, healthcare sites may choose to restrict the number of visitors or family members that can accompany a patient to their appointment. Any visitors that accompany a patient to a facility need to be screened and follow the same guidelines as patients and healthcare workers. The American Academy of Audiology recommends that patients should come to appointments alone when possible and are only accompanied by one individual when this is not possible (AAA, n.d.).

As of November 2021, staff working at a facility that receives Medicare and/or Medicaid funding must be vaccinated against COVID-19, unless exempt for religious or medical reasons (CMS, 2021). This affects all healthcare settings accepting Medicare or Medicaid funding, including hospitals and clinics (AAA, 2022). Employers should ensure that all of their employees have been fully vaccinated against COVID-19, or have a valid religious or medical exemption, and store these medical records in a secure and confidential manner. Acceptable forms of proof of vaccination include CDC COVID-19 vaccination cards, photos of the CDC vaccination cards, documentation from a healthcare provider or electronic health record, or a state immunization system record (Sholinsky et al., 2021). Practice owners should obtain guidance from lawyers on how to best comply with this mandate. Epstein Becker & Green (EBG) national law firm provides recommendations on how to comply with this ruling (https://www.ebglaw.com/insights/medicare-and-medicaid-providers-take-note-new-cms-rules-require-health-care-workers-to-be-fully-vaccinated-by-january-4-2022/).

Environmental infection prevention protocols should also be employed to reduce the risk of COVID-19 transmission (Palmore & Smith, 2022). The number of surfaces that need to be touched should be reduced when possible. Any doors that are able, should be left open to reduce the number of people touching doorknobs, and patients should not sign themselves in with a community pen. Any surfaces that are touched should be thoroughly disinfected between patients (AAA, n.d.). Surfaces should be disinfected with products approved for "emerging viral pathogens" by the Environmental Protection Agency (EPA) (EPA, 2021; Palmore & Smith, 2022).

Providing Audiology Services to Patients with Active COVID-19 Infection

The recommended assessment and treatment protocol differs from those who have recovered from the infection and those who present with a suspected or confirmed active COVID-19 infection. Treatment protocols may vary depending on the setting and the chief complaint of the patient. Once patients have recovered from the COVID-19 infection, they should be seen in an audiology practice for a more comprehensive evaluation.

Sudden Sensorineural Hearing Loss

Should a patient with an active suspected or confirmed COVID-19 infection present with complaints of a sudden hearing loss, they need to be assessed immediately and, if applicable, receive treatment as soon as possible. Patients with a sudden sensorineural hearing loss have a better prognosis if they receive the appropriate treatment within six days (Chang et al., 2005).

However, sudden sensorineural hearing loss in patients with an active COVID-19 infection poses unique challenges. COVID-19 positive patients who are not currently admitted to a hospital should be evaluated and treated at a facility that is able to undertake the proper precautions. A COVID-19 positive patient should be seen at a time where other patients are not

present, when possible, or in a separate location within the facility if diagnostic equipment is not needed (e.g., follow-up counseling).

The test battery for suspected sudden sensorineural hearing loss in patients with an active infection may need to be reduced in order to limit potential exposures. At minimum, otoscopy, tympanometry, and air and bone conduction pure tone threshold testing should be performed. If otoscopy or tympanometry is abnormal, or if there are air-bone gaps present, then other pathologies, such as otitis media, need to be ruled out. If a sudden sensorineural hearing loss is confirmed, the patient needs to be referred for medical treatment immediately.

Sudden sensorineural hearing loss is most commonly treated with high dose corticosteroids. Steroids can be administered systemically with oral medication, and/or with intratympanic injections. The American Academy of Otolaryngology – Head and Neck Surgery clinical practice guidelines (Chandrasekhar et al., 2019) recommend that clinicians refer patients for magnetic resonance imagery (MRI) or ABR to rule out retrocochlear lesions whenever possible.

If a sudden hearing loss exists in a hospitalized patient with an active COVID-19 infection, the patient should be treated immediately with high dose corticosteroids. Since the patient is already hospitalized in a facility equipped to care for COVID-19 positive individuals, access to treatment may be simpler than non-hospitalized patients. The same PPE recommendations that exist for outpatient patients receiving treatment in a facility apply to hospitalized patients as well.

Outpatient Patient Management

If a patient is identified as potentially being COVID-19 positive through case history, symptom screening questionnaires, or temperature checks, or has tested positive for the virus, the

patient should not be seen in the audiology facility, except in emergency situations. For non-emergency cases, the patient should be rescheduled for a later date once they have completed the recommended isolation period and are no longer infectious. Once recovered, these patients can be managed based on the recommendations for providing audiology services to recovered COVID-19 patients, as described on page 67 of this manuscript.

If a COVID-19 positive patient needs to be seen, anyone who comes into contact with the patient needs to be in proper personal protective equipment (PPE). The Government of the District of Columbia recommends using respirators, such as N95, powered air-purifying respirators (PAPRs), and elastomeric respirators. These are the most effective respiratory protection for healthcare workers providing care to patients with suspected or confirmed COVID-19. Other recommended PPE to utilize when treating COVID-19 positive patients include eye protection, gloves, and gowns. If a respirator is not available, a face mask can be substituted. Face shields can be utilized in addition to masks or respirators, but not as a substitute since they do not provide adequate respiratory droplet source control. Eye protection may be removed only when they would interfere with the medical procedure, such as when using an otoscope (DC Health, 2021).

Hospitalized Patient Management

Patients who are experiencing auditory or vestibular effects of a COVID-19 infection while they are hospitalized may be managed in a different way. Otoscopy and tympanometry should be performed first. For patients with severe or critical illness, moving the patient to a sound booth for pure tone testing may not be possible. In these instances, bedside screening may be conducted at a level that takes into account the ambient noise octave band levels, such as 20 or 25 dB HL. Threshold testing is likely not possible, due to ambient noise issues. Behavioral

audiometry should be used for patients who are alert enough to provide reliable behavioral responses. This may involve bedside testing with a portable audiometer, or preferably using boothless audiometry systems that monitor ambient noise levels and utilize active noise reduction to mitigate background noise (Tuten et al., 2020). The use of whispered speech, tuning fork tests, and other bedside measures should not be used alone to determine the presence or absence of hearing loss, as they have poor sensitivity and variable predictive value of true hearing thresholds (Boatman et al., 2007). Otoacoustic emissions or auditory evoked potential testing with portable equipment may be utilized when behavioral testing is not possible, or to supplement behavioral findings.

Bedside vestibular tests may be performed as well, such as ocular motility, head impulse/thrust test, dynamic visual acuity test, headshake test, Romberg test, Fukada stepping test, hyperventilation-induced nystagmus test, and Valsalva induced nystagmus test (Hale et al., 2015).

Providing Audiology Services to Recovered COVID-19 Patients

A patient who has recovered from a COVID-19 infection and who has completed the CDC recommended isolation guidelines may be seen in an audiology clinic, just like any other patient. When the COVID-19 patient is seen, a more detailed case history should be taken, and a unique battery of tests may be performed to address the patient's chief complaint(s).

Case History Considerations

The case history form for a patient who has recovered from COVID-19 will likely need to include questions that are not routine when obtaining the standard audiologic case history (Limb & Ackley, 2007). A standard case history form should include questions about whether a

patient has a history of COVID-19 infection and help the audiologist determine if the onset of their auditory/vestibular dysfunction aligns with that COVID-19 infection timeline.

Before evaluating and treating post-COVID-19 patients, it is important to know the severity of their illness and whether or not they were hospitalized. Hospitalized patients are more likely to have been placed on a ventilator, which may increase the risk of hearing loss. Endotracheal, nasotracheal, or tracheal tube ventilation is not thought to cause hearing loss itself, but positive pressure ventilation may contribute to hearing loss due to excessive pressure being transmitted rapidly through the Eustachian tube and resulting in tympanic injury via the middle ear and conductive hearing loss (Halpern et al., 1999). Hospitalized patients are also more likely to have been treated with ototoxic drugs which may also have effects on the auditory and vestibular systems. It may also be useful to inquire about any long-COVID-19 symptoms that a patient may be experiencing. For patients experiencing new or worsened tinnitus, a tinnitus handicap scale should be given. See Appendix A for a suggested COVID-19 case history form.

Auditory Test Battery for Recovered COVID-19 Patients

Otoscopy

Otoscopy should be performed to look for any abnormalities of the external ear canal or tympanic membrane. Otitis media has been reported as a result of a COVID-19 infection (Raad et al., 2020), which may be evident on otoscopy.

Conventional Pure Tone Testing

Behavioral pure tone threshold testing in the conventional audiometric frequencies from 250 to 8000 Hz should be completed whenever possible. DiSogra (2021a) reports that the most

common type of COVID-19 hearing loss is bilateral sensorineural hearing loss in the high frequencies.

Extended High Frequency Pure Tone Testing

Extended high frequency pure tone testing of frequencies above 8,000 Hz should be added to the test battery for COVID-19 patients. Hearing loss resulting from a COVID-19 infection, similar to other viral infections or ototoxicity, may affect the highest frequencies first. Gedik et al. (2021) found that individuals who have had COVID-19 had elevated mean hearing threshold values in the extended high frequencies (10k to 16k Hz) when compared to individuals who have not had COVID-19.

Tympanometry

Tympanometry is an objective measure of acoustic admittance of the middle ear and air pressure in the ear canal (Hunter & Sanford, 2015). Tympanometry should be performed to rule out potential outer/middle ear abnormalities that could be contributing to a patient's hearing loss. Since most COVID-19 related hearing loss is sensorineural in nature (Almufarrij & Munro, 2021), it would be expected that most patients have Jerger Type A tympanograms, where pressure and compliance are within normal limits unless they have developed otitis media.

Otoacoustic Emissions

Otoacoustic emission (OAE) testing should be part of the COVID-19 audiometric test battery to objectively assess cochlear outer hair cell function. OAEs are thought to show early cochlear damage that may not yet be evident with standard pure-tone audiometry. OAEs are sensitive to early noise induced hearing loss and ototoxicity (Lucertini et al., 2001), and may catch early viral-mediated cochlear damage as well. Both TEOAEs and DPOAEs may be affected. Bozdemir et al. (2022) found that both TEOAE and DPOAE amplitudes are

significantly reduced at some frequencies in patients who have recovered from COVID-19 when compared to a control group.

Acoustic Reflex Thresholds

Acoustic reflex threshold (ART) testing is useful in cross-checking behavioral results and helping to differentiate middle ear, cochlear, retrocochlear, and other sites of lesions (Feeney & Schairer, 2015). Acoustic reflex testing should be included in a COVID-19 test battery as well. It has been hypothesized that acoustic reflexes may be absent in COVID-19 patients due to peripheral hearing loss or brainstem involvement (DiSogra, 2021a,2021b). In contrast, Resuli et al. (2021) evaluated acoustic reflex thresholds in COVID-19 patients with taste disorders. The researchers found that acoustic reflex thresholds are present in individuals who have had COVID-19, but that ARTs are significantly elevated at 500 Hz, 1k Hz, 2k Hz, and 4k Hz as compared to healthy subjects.

Speech Testing

Speech audiometry, such as speech recognition threshold (SRT) and word recognition, should be included in a COVID-19 test battery to cross check behavioral pure-tone test results, determine the type of hearing loss and assess central auditory function (McArdle & Hnath-Chisolm, 2015). Speech audiometry results will likely be consistent with hearing sensitivity, but if word recognition scores (WRS) are disproportionately poor, then an auditory processing evaluation may be warranted (DiSogra, 2021a).

A summary of expected audiometric test results for COVID-19 related SNHL can be found in Table 7.

Table 7

Expected Audiometric Test Results for COVID-19 Related Sensorineural Hearing Loss

Audiometric Test	Expected Findings
Otoscopy	Normal
Tympanometry	Pressure and compliance within normal limits
Otoacoustic Emissions	Reduced TEOAE and/or DPOAE amplitudes
Acoustic Reflex Thresholds	Likely elevated or absent
Speech Testing in Quiet	Consistent with hearing sensitivity. Word recognition may be disproportionately poor if auditory processing issues exist.
Pure tone threshold testing	Any degree and configuration of SNHL may exist Bilateral, high frequency SNHL is thought to be most common

Vestibular Test Battery for Recovered COVID-19 Patients

Videonystagmography

Videonystagmography (VNG) measures nystagmus during a series of tests of oculomotor function, gaze stabilization, vestibulo-ocular reflex tests, and other specialized tests, such as the Dix-Hallpike (Harris et al., 2019). In recovered COVID-19 patients who are experiencing symptoms of vestibular dysfunction, a variety of VNG abnormalities may be present. In a study by Pazdro-Zastawny et al. (2022), patients who had complaints of vertigo after recovering from a mild to moderate COVID-19 infection (diagnosed by PCR test) underwent VNG evaluations. During the VNG testing, 13.8% of participants had spontaneous nystagmus without vision (n=8), 24.1% had positional nystagmus (n=15), and asymmetrical optokinetic nystagmus was observed in 31% of patients (n=18). In 53.4% of patients, abnormal VNG findings suggested a central pathology, perhaps due to COVID-19 related damage to the central nervous system. Recovered

COVID-19 patients with vestibular dysfunction may demonstrate asymmetrical caloric responses (Abdelrahman & Shafik, 2021). In the study by Pazdro-Zastawny et al. (2022), 39.7% (n=23) had a unilateral weakness on caloric irrigations, and 95.7% (n=22) of those patients with unilateral weakness demonstrated directional preponderance contralateral to the unilateral weakness. This suggests that COVID-19 may also lead to peripheral vestibular dysfunction, perhaps with direct damage to the vestibular organs (Abdelrahman & Shafik, 2021).

Vestibular Evoked Myogenic Potentials

Vestibular evoked myogenic potentials (VEMPs) assess the integrity and function of the vestibular pathways in the brainstem and are sensitive to the detection of central lesions. Cervical VEMPs (cVEMPs) test the ipsilateral saccule and inferior vestibular nerve by measuring the vestibulo-collic reflex in response to sound. Ocular VEMPs (oVEMPs) test the contralateral utricle and superior vestibular nerve by measuring the vestibulo-ocular reflex in response to sound (Yılmaz et al., 2021).

Cervical VEMP. It has been reported that recovered COVID-19 patients with vestibular dysfunction may have abnormal cVEMPs. Afshari (2021) reports a case where a COVID-19 positive patient had an inter-aural amplitude asymmetry ratio of 60% on cVEMP, which is a clinically significant finding. Tan et al. (2022) also found abnormal asymmetry ratios in COVID-19 positive patients compared to a control group. Yılmaz et al. (2021) found that recovered COVID-19 patients are more likely to have abnormal cVEMP responses than the age and sex matched control group who have never had a COVID-19 infection. In this study, cVEMPS were absent bilaterally in 5.4% (n=2) and unilaterally in 5.4% (n=2) of recovered COVID-19 patients. Additionally, the P1/N1 amplitudes were significantly decreased in the recovered COVID-19 group compared to the control.

Ocular VEMP. In the same study, Yılmaz et al. (2021) also found that oVEMPs were absent bilaterally in 8.1% (n=3) and unilaterally in 21.6% (n=8) of recovered COVID-19 patients. Similar to cVEMP, the recovered COVID-19 group had significantly decreased N1/P1 amplitudes on oVEMP when compared to the control group. Tan et al. (2022) reported finding abnormal amplitude asymmetry ratios for oVEMP in COVID-19 positive patients that were statistically significant from the control group.

Video Head Impulse Test

The Video Head Impulse Test (vHIT) assesses the vestibulo-ocular reflex (VOR) and the function of the semicircular canals, motor nuclei in the brainstem, and extraocular muscles (Stevens et al., 2017) by detecting saccades in response to high acceleration head movements (Yılmaz et al., 2021). There have been mixed reports in the literature on what vHIT results occur in recovered COVID-19 patients who are complaining of vestibular dysfunction. Tan et al. (2022) found a significant difference in vHIT lateral gain, LARP gain, and RALP gain measurements between COVID-19 positive individuals and COVID-19 negative individuals, where COVID-19 positive individuals had lower gain than the COVID-19 negative control group. Yılmaz et al. (2021) also reported significantly decreased vHIT gains (specifically in the vertical semicircular canals) in recovered COVID-19 patients compared to a control. However, Gallus et al. (2021) and Fancello et al. (2022) reported normal vHIT findings in recovered COVID-19 patients, with the exception of two patients in the study by Fancello et al. who had abnormal findings. There is no clear pattern of expected vHIT results in COVID-19 patients, but performing this test still has clinical utility, as it provides information about the vestibular system integrity and may reveal any vestibular hypofunction that may exist (Stevens et al., 2017).

A summary of the expected vestibular test findings for COVID-19 related vestibular dysfunction can be found in Table 8.

Table 8

Expected Vestibular Test Results for COVID-19 Related Vestibular Dysfunction

Vestibular Test	Expected Findings
VNG	May have spontaneous nystagmus May have positional nystagmus Asymmetric optokinetic responses
VNG – Calorics	Unilateral weakness Directional preponderance
cVEMP	Abnormal amplitude asymmetry ratio Reduced N1/P1 amplitudes Absent cVEMP
oVEMP	Abnormal amplitude asymmetry ratio Reduced P1/N1 amplitudes Absent oVEMP
vHIT	Highly variable May be within normal limits May have decreased gain

Rehabilitation Considerations

In cases of sudden sensorineural hearing loss, patients need to be treated with high dose corticosteroids, either administered systemically or via intratympanic injections. Systemic corticosteroids should be administered at a suggested dose of 1 mg/kg per day for 7 to 14 days. Intratympanic steroids may also be administered at the time of onset but may also be recommended after a failed initial therapy within 2 to 6 weeks. The recovery rate of hearing sensitivity is nearly equivalent for systemic and intratympanic corticosteroids (Chang et al., 2021). If treatment does not restore hearing sensitivity to within normal limits and the patient is left with a permanent sensorineural hearing loss, the patient can be managed with amplification.

Once the hearing loss is stable, patients may be fit with hearing aids or undergo cochlear implant evaluation depending on the degree of hearing loss. Patients may need assistive listening devices while they are receiving treatment or waiting for hearing sensitivity to stabilize.

Patients with stable sensorineural hearing loss can be managed in the same ways as typical patients, with some form of amplification. Patients with new onset hearing loss, especially after dealing with a possibly life-threatening infection, may need additional counseling. Patients may need additional counseling on communication strategies, especially in a COVID-19 environment where face masks and distancing may pose additional communication challenges (Oosthuizen et al., 2022).

Vestibular disorders occurring as a result of COVID-19 may need to be treated with vestibular rehabilitation therapy (VRT). VRT consists of repetitive, systematic exercises that help to reduce or eliminate motion-provoked vestibular symptoms to improve postural stability and overall equilibrium (Gans, 2015). Afshari (2021) reports using vestibular rehabilitation therapy to treat a patient with COVID-19 induced otolith dysfunction, with significant improvement in patient symptoms.

Patients who are facing a multitude of long-COVID-19 issues may need referrals to other specialists to address their needs or to a psychiatrist to address the emotional difficulties associated with chronic illness. Online resources and support groups are available for COVID-19 long-haulers, such as C19 Recovery Awareness (https://www.c19recoveryawareness.com/). Post-COVID-29 rehabilitation and recovery services are available for individual suffering with long COVID-19, such as one available from UW Medicine (https://www.uwmedicine.org/specialties/post-covid-rehabilitation)

Summary

COVID-19 patients may present to audiologists with complaints of auditory or vestibular dysfunction, whether they present with a sudden sensorineural hearing loss during an active COVID-19 infection (Edwards et al., 2021; Kilic et al., 2020; Koumpa et al., 2020; Ricciardiello et al., 2021), or vertigo after recovering from the infection (Saniasiaya & Kulasegarah, 2021; Viola et al., 2021). By following these recommendations, audiologists should be prepared to assess and treat this population appropriately. The body of literature on the auditory and vestibular effects of COVID-19, and how to manage these patients, is growing, and audiologists need to critically review the literature to make clinical decisions for patients with COVID-19 related auditory and vestibular system dysfunction.

CHAPTER 3

CRITICAL REVIEW OF THE LITERATURE

Assessment of Existing Literature

The early literature (March 2020 to December 2020) on the auditory and vestibular effects of COVID-19 consists mostly of individual case reports and short notes on preliminary observations. The first reports of hearing loss related to a COVID-19 infection emerged in May 2020, two months after the World Health Organization declared COVID-19 a worldwide pandemic (Balkhair, 2020). In a note to the editor of the American Journal of Otolaryngology, Sriwijitalai and Wiwanitkit out of Thailand reported on a patient who had a COVID-19 infection on March 15, 2020, who coincidentally presented with a neurosensory hearing loss. As the patient recovered, there was no change in her hearing status. This early preliminary report was described as the first world report on the interrelationship between hearing loss and COVID-19 (Sriwijitalai & Wiwanitkit, 2020). Case reports are valuable in initiating investigations regarding the possible auditory and vestibular effects of COVID-19, but the case report information cannot be broadly generalized and may be influenced by biases and confounding variables. The early case reports (e.g., Fidan, 2020; Koumpa et al., 2020; Raad et al., 2020) brought attention to the possible auditory and vestibular effects of COVID-19 and highlighted the need for more comprehensive research studies to take place.

The early literature published in 2020 also began to include cross-sectional research studies. In May 2020, Mustafa investigated the audiological profile of asymptomatic COVID-19

patients using a cross-sectional study design. Participants were excluded from the study if they had a history or hearing loss or a history of any known cause of hearing loss. However, it was not explicitly stated whether other variables that may have contributed to hearing loss, such as noise exposure, ototoxic medications, or other concurrent illnesses, were controlled for in the study (Mustafa, 2020). Many of the cross-sectional studies (Dror et al., 2020; Stavem et al., 2020, etc.) excluded patients who had pre-existing complaints of auditory or vestibular dysfunction but did not control for other potential causes of hearing loss, tinnitus, or vestibular disorders, and results of the studies need to be interpreted with caution.

As the database of case reports, cross-sectional studies, and anecdotal reports and notes continued to grow, literature reviews began to be published. In June 2020, Almufarrij et al. published one of the first rapid systematic reviews discussing whether COVID-19 has an affect on the auditory and vestibular systems. In this review, five case reports and two cross-sectional studies were reviewed and analyzed. Within this study, the authors assigned a quality rating to the case reports and cross-sectional studies that they analyzed. Four sources were given a quality rating of fair (Cui et al., 2020; Fidan, 2020; Han et al., 2020; Lechien et al., 2020), and three were poor (Mustafa, 2020; Sriwijitalai & Wiwanitkit, 2020; Sun et al., 2020). Systematic literature reviews are a valuable resource, as they serve to inform the scientific community regarding the strength of the association between COVID-19 and auditory and vestibular dysfunction. As more case reports and small-scale studies were published, more in-depth literature reviews emerged that analyzed higher-quality sources (e.g., Aggarwal et al., 2022; Kaliyappan et al., 2022, etc.).

Current COVID-19 literature (late 2021 to late 2022) has evolved to include experimental studies comparing an experimental group with a control group, in addition to case reports and

cross-sectional studies. As the complexity of the types of literature available on COVID-19 and the auditory and vestibular systems increases, the quality of the evidence increases as well. AlJasser et al. (2022) recognized the need for studies that specifically investigate changes in auditory or vestibular function pre- and post-COVID-19 infection, with appropriate control groups to compare against. In this study, researchers measured auditory and vestibular symptoms, relative to an individual's baseline pre-COVID-19 infection. The researchers in this study also compared symptoms during the acute and recovery phases of COVID-19 and symptoms in individuals with mild and severe illness and used statistical analyses to compare to a control group. This type of research study accounts for many variables that may affect auditory and vestibular function in individuals with COVID-19, and often produces higher quality, more valid and generalizable results.

Research Challenges

There are many challenges with conducting research on the auditory and vestibular effects of COVID-19 that may affect the quality of the literature available on the topic. It is difficult to conduct research on COVID-19 positive patients due to concerns of transmission, COVID-19 is constantly evolving, and there are many other variables at play that may contribute to any auditory or vestibular effects seen in COVID-19 patients. These include the administration of ototoxic medications, lack of oxygen, concurrent noise exposure, other concurrent viral infections, and prolonged bed rest. It is difficult to isolate and control these variables in order to determine whether or not the auditory or vestibular dysfunction is directly attributed to a COVID-19 infection.

Especially in the early stages of the pandemic, research on the auditory and vestibular effects of COVID-19 positive patients was limited due to safety concerns. In Spring 2020, many

scientists and researchers were sent home, and laboratories and clinical research activities were put on pause (Cook & Lauer, 2021). Even once individuals began returning to work, direct access to patients who were positive for COVID-19 may not have been possible due to concerns for virus transmission and the lack of appropriate PPE.

COVID-19 is constantly evolving, both in the virus itself as it mutates and produces new variants, and in the public health perspective as scientists learn more about how the disease spreads. As the virus that causes COVID-19 mutates and new variants are created, the potential auditory and vestibular effects of that variant may potentially change as well. This is a challenge to track and control.

Future Directions

COVID-19 research has come a long way since the emergence of the disease in December 2019, but it still has a long way to go, especially as the virus becomes endemic. In order to better understand the effects that COVID-19 may have on the auditory and vestibular systems, there is a need for more complex and controlled research studies. Research is needed that controls for other potential causes of auditory or vestibular dysfunction, such as age-related hearing loss, noise induced hearing loss, ototoxicity, other infections, or prolonged bed rest. The use of age and sex matched control groups and comparing test results pre- and post- COVID-19 infection in the same individual may be able to provide better control for some of the potential variables. This becomes exceedingly difficult as we enter a stage where individuals have experienced multiple COVID-19 infections (Wang et al., 2021). There is also a need for longitudinal research studies to investigate the effects of COVID-19 infection on individuals over a longer period of time to investigate if the auditory and vestibular effects of COVID-19 are temporary, fluctuate or stabilize over time.

Further research is needed that investigates the auditory and vestibular effects of COVID-19 infection that accounts for variables such as vaccination status, weakened immune systems, and variants of the virus. More research is needed to investigate these variables, as well as others, which may contribute to why some patients present with auditory or vestibular dysfunction and others do not.

There is limited literature available regarding the auditory processing effects of COVID-19, even though proposed theories of the pathophysiology of the auditory and vestibular effects of COVID-19, such as hypoxia of the hearing centers in the brain, suggest a central auditory dysfunction. DiSogra (2022) hypothesizes that the "brain fog" symptoms that COVID-19 survivors often experience is related to an auditory processing disorder. More research is needed to test DiSogra's hypothesis, and to investigate whether or not COVID-19 could contribute to an auditory processing disorder.

Further research is also needed on the possible vestibular effects of COVID-19. There are reports of dizziness or vertigo after COVID-19 infection, as well as COVID-19-induced BPPV or vestibular neuritis, but there is limited data published on specific vestibular tests other than ENG/VNG findings. This data would be valuable in helping to determine if COVID-19 related vestibular dysfunction is peripheral, central or both peripheral and central in nature. Understanding the relationship between COVID-19 and vestibular dysfunction would also help audiologists determine which vestibular tests are useful in including in a vestibular test battery for COVID-19 patients and inform vestibular rehabilitative strategies.

Since the beginning of the COVID-19 pandemic, there have been published research articles on the potential auditory and vestibular effects of the virus. The quality of the literature

has improved over time as scientists learned more about COVID-19, but more research is needed to truly understand the relationship between COVID-19 and the auditory vestibular systems.

Summary

SARS-CoV-2, the virus that causes COVID-19, emerged in late 2019 and was declared a worldwide pandemic on March 11, 2020 (Balkhair, 2020). Since then, this highly contagious virus has infected more than 600 million individuals (WHO, 2022b) and has changed the way that the world functions. In addition to many other systemic effects, there have been reports of COVID-19 associated auditory and vestibular dysfunction (e.g., AlJasser et al., 2022; Tan et al., 2022). There is an estimated prevalence COVID-19 related auditory and vestibular dysfunction:7.6% for hearing loss, 14.8% for tinnitus, and 7.2% for vertigo (Parrino et al., 2022). Sensorineural hearing loss or sudden sensorineural hearing loss and changes in tinnitus are the most common auditory effects. Conductive or mixed hearing losses are less common (Almufarrij & Munro, 2021). Vestibular dysfunction can occur as shown by VNG abnormalities, suggesting a central cause (Pazdro-Zastawny et al., 2022) or as positional nystagmus and/or unilateral caloric weakness suggesting a peripheral cause (Abdelrahman & Shafik, 2021). Other reported vestibular effects include BPPV (Picciotti et al., 2021) and vestibular neuritis (Mat et al., 2021). Because COVID-19 infection may affect the auditory and vestibular systems, audiologists need to be informed and prepared to safely assess and treat this unique population without putting themselves at risk for being infected by COVID-19.

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APPENDIX A

COVID-19 CASE HISTORY FORM

COVID-19 Case History

COVID-19 History

Have you ever been diagnosed with COVID-19? ☐ No ☐ Yes ☐ Unsure

Have you been fully vaccinated against COVID-19? ☐ No ☐ Yes

Which vaccine? _____

Have you received any additional booster doses of the COVID-19 vaccine? ☐ No ☐ Yes

Were you fully vaccinated at the time of COVID-19 infection? ☐ No ☐ Yes

How were you diagnosed? ☐ At home antigen test ☐ PCR Test

Name of physician who coordinated your COVID-19 diagnosis and care: _____

When did you test positive for COVID-19? _____

How long did your symptoms last? _____

Please check any COVID-19 symptoms or complications that you experienced:

☐ "Brain fog"
☐ Cardiac arrest
☐ Chest pain
☐ Chills
☐ Confusion
☐ Congestion
☐ Cough
☐ Diarrhea
☐ Difficulty breathing
☐ Fatigue
☐ Fever
☐ Headache
☐ Inability to stay awake or wake up
☐ Loss of smell
☐ Loss of taste
☐ Muscle aches
☐ Nausea
☐ Organ dysfunction
☐ Pale, gray, or blue skin
☐ Septic shock
☐ Shortness of breath
☐ Sore throat
☐ Vomiting
☐ Other, please explain:
_____
_____
_____

How would you classify your illness at the time when you felt the worse?

☐ Asymptomatic ☐ Mild ☐ Moderate ☐ Severe ☐ Critical

Were you hospitalized? ☐ No ☐ Yes

If yes, for how long?_____

Were you placed on a ventilator? ☐ No ☐ Yes

If yes, for how long? _____

Please list any medications you took over the course of your illness to treat COVID-19 (including supplements, natural remedies, and over the counter medications):

Medication Name	Prescribed/taken for	Duration of use
1.		
2.		
3.		
4.		
5.		

Have you experienced or been diagnosed with any long-COVID-19 symptoms? ☐ No ☐ Yes, please explain:

_____

_____

Is there anything else of importance that you'd like to share about your COVID-19 illness?

_____

_____

COVID-19 Hearing History

Have you noticed a change in your hearing since having COVID-19?

☐ No ☐ Yes

Which ear did you notice a change in? ☐ Right ☐ Left ☐ Both

How did the change in your hearing occur? ☐ Gradually ☐ Suddenly ☐ Fluctuating

How would you describe your hearing? ☐ Excellent ☐ Average ☐OK ☐ Poor ☐ No hearing

COVID-19 Tinnitus History

Have you noticed new or increased tinnitus since having COVID-19?

☐ No ☐ Yes, please explain: _____

Which ear do you experience your tinnitus in? ☐ Right ☐ Left ☐ Both

How would you describe your tinnitus? (please check all that apply)

☐ Buzzing
☐ Constant
☐ Intermittent
☐ Pulsating
☐ Ringing
☐ Roaring
☐ Swishing
☐ Other: _____

How loud is your tinnitus?

Very soft ---------- Very loud

Vestibular History

Have you noticed new or increased dizziness or balance problems since having COVID-19?

☐ No ☐ Yes, please explain:_____

Please check all that apply when you are experiencing these problems:

☐ Dizziness	☐ Rocking/tilting	☐ Headache/Migraine
☐ Spinning/rotational vertigo	☐ Unsteadiness	☐ Visual changes
☐ Lightheadedness	☐ Nausea	☐ New/increased tinnitus
☐ Falling	☐ Vomiting	

When did your symptoms begin? _____
How did your symptoms begin? ☐ Gradual ☐ Sudden

How would you describe your dizziness? ☐ Constant ☐ Episodic ☐ Other: _____

If it is episodic, how long does the dizziness last?

☐ < 90 seconds ☐ Minutes ☐ Hours ☐ Days ☐ Other: _____

Does movement or any specific activities trigger your dizziness?

☐ No	☐ Heavy lifting/straining	☐ Other: _____
☐ Bending forward	☐ Loud sounds	_____
☐ Coughing/sneezing	☐ Physical activity	_____
☐ Driving/riding in car	☐ Rolling over in bed	_____
☐ Fast neck turn	☐ Walking	_____
☐ Gazing upwards		

Auditory Processing History

Have you noticed any of the following since having COVID-19 that you did not have before your infection?

☐ Difficulty hearing in background noise	☐ Difficulty with memorization
☐ Easily distracted	☐ Difficulty concentrating
☐ Needs information repeated	☐ Need longer to process information
☐ Difficulty remembering long instructions	☐ Spelling, reading, writing difficulties
☐ Difficulty following conversations	☐ Hypersensitivity to loud sounds
☐ Difficulty with rapid speech	☐ “Brain Fog