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Bacterial co-infections and secondary infections in COVID-19: An integrative review of the clinical features, pathogens, risk factors and implications on the rational use of antimicrobials

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Abstract
Co-infections and secondary bacterial infections in COVID-19 are clinical complications associated with high mortality, which require immediate pharmacological treatment with antibiotics, in addition to the prevention and containment measures to prevent the spread of bacterial pathogens among those infected with SARS-CoV-2, mainly in hospitals and intensive care units. However, due to the emerging nature of COVID-19, little is known about co-infections and secondary infections in COVID-19. Therefore, this literature review gathered information on the forms of clinical presentation of bacterial co-infections and secondary infections in COVID-19 bacterial co-infection/secondary infections, as well as laboratory tools that can support clinical decision-making and guide the rational use of antibiotics, since the non-rational use of this pharmacological class has serious consequences for public health concerning the promotion of bacterial resistance.

Keywords: Co-Infection, secondary infection, SARS-CoV2, bacterial pathogens

Introduction
The success in the clinical management of infectious diseases and their complications depends on the basis that allows for the correct choice of treatment with selection of the appropriate antimicrobial drug, considering a variety of factors that play a part in the selection of the appropriate antimicrobial drug such as scientific evidence on safety and effectiveness, a correctly prescribed prescription, availability, and economic accessibility for the patient, and finally, adequate conditions at the time of dispensing along with suitable information to promote the correct use [1-3]. Moreover, the correct diagnosis and identification of risk factors are critical for making clinical decisions relevant to therapeutic effectiveness and prevention activities [4-6].
In this context, co-infection is a term that designates the simultaneous occurrence of two or more infections by different pathogens in an individual, while the term secondary infection describes a condition where a different infection occurs along with a previous one in the same individual [7-8]. Constituting both cases a significant clinical challenge in the scope of the diagnosis and choice of pharmacological treatments, also representing a challenge for the surveillance services in detecting sources of contamination/infection and application of control/prevention measures in the community and hospital environments [9].
Regarding the COVID-19 (infection by the SARS-CoV-2 virus), an emerging disease that humanity experiences for the first time, information on cases of co-infections and secondary infections, concerning their clinical and epidemiological features, are scarce [10-13]. Therefore, this study reports the main clinical presentations on bacterial co-infections/secondary infections in COVID-19, and the pathogens described in the literature. After gathering pieces of information relevant for the identification of these complications in COVID-19, it will better guide clinical decision making.

SARS-CoV-2 pathogenesis and clinical manifestations
COVID-19 pathology is highly transmissible and unpredictable concerning its clinical evolution that can range from mild symptoms to severe respiratory distress. Therefore, beyond measures to reduce the transmissibility, research for a greater understanding of

aggravations related to chronic comorbidities and diseases as well as co-infections/secondary infections is required. This will improve the health systems and service activities in fighting this viral disease of pandemic magnitude and emerging character [14-16].

In the pathology caused by the SARS-CoV-2, the most common symptoms are fever, nonproductive cough, myalgia, fatigue with abnormal chest findings on computed tomography, and loss/decrease of the senses of smell and taste. Less frequent symptoms include productive cough with or without blood, headaches, and diarrhea [15-17]. However, It must be highlighted that there are asymptomatic cases of COVID-19 [18], as well as inter-individual variability in symptom manifestation of COVID-19 [19], which tends to be more severe in cases of old age, presence of chronic diseases such as diabetes, cardiorespiratory disorders, cancer, obesity, other comorbidities, and smoke. These risk factors and chronic diseases may increase the risk of developing acute respiratory syndrome which can lead to death [20, 21].

In this sense, COVID-19 is an acute respiratory syndrome (Figure1) that results from the replication of the SARS-CoV2 virus in the type II pneumocytes, which are cells responsible for the production and secretion of surfactant. [22]. When these cells are injured or killed, they release damage-signaling molecules with pro-inflammatory activity that accentuates the inflammation in the lungs, causing pulmonary edema that critically compromises the hematosis process, which could further lead to emergency and admission to an intensive care unit [23, 24].

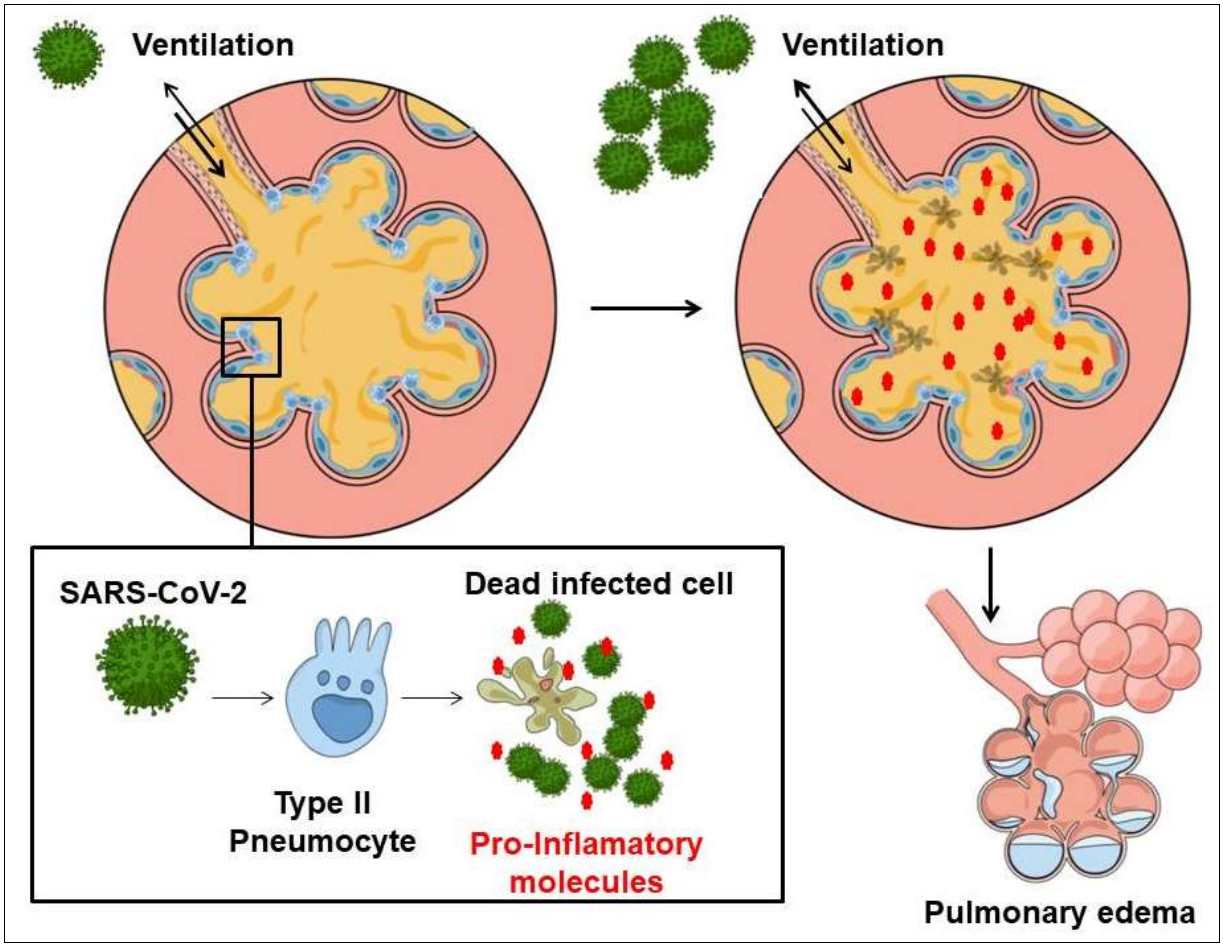

Fig 1: Severe acute respiratory syndrome pathogenesis. The SARS-CoV-2 virus infect type II pneumocytes that die and release pro-inflammatory molecules, increasing inflammation and causing pulmonary edema (fluid accumulation in the lungs), which leads to several complications due impaired gas exchanges

It has been noted the SARS-CoV-2 infection affects the immunological and respiratory system, also producing systemic effects on the kidneys, the liver, the blood, the cardiovascular system, and the nervous system, resulting in several health complaints that endure months after the resolution of the infection [25-30].

In addition, there are cases of reinfection by the SARS-CoV-2 with symptoms of higher intensity [31, 32], indicating gaps in the comprehension of the evolution and biological diversity in the strains of SARS-CoV-2, as well as the features of the host-pathogen interaction concerning the cellular pathways involved in the development of immunological memory after infection.

Clinical presentation and features of bacterial co-infections/secondary infections in COVID-19

Co-infections and secondary bacterial infections in SARS-CoV-2 can be asymptomatic or have symptoms distinct from isolated SARS-CoV-2 infection, involving several variations that hinder both the diagnosis of COVID-19 and bacterial co-infection/secondary infection [12, 33-34]. In cases in which the patient has advanced age, admission to the ICU with mechanical ventilation, use of venous or urinary catheters, treatment with corticosteroids, as well as chronic comorbidities such as diabetes, high blood pressure, heart disease, and infection by the HBV and/or HIV viruses can

all be associated with severe clinical states and high mortality [11, 35-42].

Moreover, large patient flows between different hospitals are also reported as possible risk factors for bacterial co-infections / secondary infections in COVID-19 [43].

Concerning clinical findings of diagnostic value for bacterial co-infections/secondary infections in COVID-19, Neutrophilic leukocytosis is considered a hematological marker since, in isolated COVID-19, there are typically no changes in neutrophil counts [44, 45]. Furthermore, beyond microbiological culture, laboratory tests such as the quantification of interleukin 6, interleukin 1 β, calcitonin, tumor necrosis factor α, and ferritin levels can also be useful in the detection of bacterial co-infections/secondary infections in COVID-19, when they present abnormally high values [42, 44].

Moreover, some typical laboratory tests for the diagnosis of bacterial infections, such as the anti-streptolysin O test, pro-calcitonin and the speed of blood sedimentation can present inconclusive results [44, 46]. Therefore, a set of laboratory tests must be selected instead of a single one to avoid the non-detection of the complication in COVID-19.

Regarding imaging exams, in most cases on radiographs, the typical pattern of COVID-19 with bacterial respiratory infection presents opacity in the lobar or segmental space in the lungs, whereas, in computed tomography exams, the observation of segmental or focal dense consolidation with or without frosted glass opacity is common [12, 46-48].

However, bacterial co-infections/secondary infections in COVID-19 are not restricted to the respiratory tract, existing records of bacterial infections affecting the nervous system [49-51], the urinary system [36, 38, 52, 53], the gastrointestinal system [36, 54, 55], soft tissue [53], the bloodstream [36, 39, 53, 56], cellulite and endocarditis [57], caused by a wide variety of bacterial pathogens (Table 1).

Therefore, high attention to suspicious cases of co-infection/secondary infections with the employment of a set of clinical and laboratory exams can better guide clinical decisions regarding treatment and prevention strategies to avoid the spread of bacterial pathogens among those infected by the SARS-CoV-2 virus.

Bacterial pathogens reported in co-infections/secondary infections in COVID-19 and its implications over antibiotic therapy

A large proportion of patients with COVID-19 may require hospitalization, in which antimicrobials are used empirically, indiscriminately, and excessively (especially azithromycin), imposing an unpredictable negative impact on bacterial resistance to antibiotics, both in the hospital and in the community [58].

Consequently, recognizing the identity of the bacterial agents and the clinical characteristics of co-infection/secondary infection cases in COVID-19 is important when choosing therapy [59, 60] because the pharmacodynamics of antibiotics can be impaired by factors such as the intrinsic resistance of the etiologic agent due to the absence of a molecular target in the bacterial cell, or the presence of resistance acquired by horizontal gene transfer mechanisms. The effect of the antibiotics can be decreased by phenotypic attributes originating from social mechanisms dependent on population density, as well as structural, metabolic and physiological features with influence over the bacterial metabolic and growth rates [61-67].

There are several factors that can interfere in the pharmacokinetic and efficacy/safety attributes of treatment with antimicrobials. Physical-chemical drug properties, vascularization of the infection site [68-70], patient age, metabolism, drug excretion profiles, as well as drug interaction between antimicrobials and drugs used for managing comorbidities and chronic diseases all play a part in antimicrobial treatment choice [71, 72]. Patient past experience could impose potentially negative effects on drug adherence to the treatment if a patient has had prior adverse drug reactions due to drug toxicity [73, 74].

In this context, a literary survey in the PubMed database with the Boolean operators COVID-19 ‘and’ Bacterial co-infection ’and’ secondary infection resulted in the selection of 70 studies, which made it possible to identify the involvement of 22 bacterial families, 23 genus, 39 species and 2 specific phenotypes of bacterial involved in co-infection/secondary infections in COVID-19 cases (Table 1), thus reinforcing the importance of requesting laboratory tests to confirm the identity of the pathogen and its profile of susceptibility to antibiotics in medical practice, which will further guide the selection of the treatment considering the clinical peculiarities of the patient that may affect the outcome of the pharmacological treatment, as well as the spectrum of activity of the antimicrobial drug.

In this context, actions, such as clinical and epidemiological surveillance of agents in co-infections / secondary infections, identification of risk factors and population groups most likely to develop co-infections / secondary bacterial infections along with control and prevention measures such as quarantine, social distancing, hand washing, use of sanitizers and personal protective equipment, are important to provide support in clinical decisions considering the rational use of medicines and prevention of new cases of the disease [58, 75-77].

Moreover, epidemiological information is also important for the different stages of pharmaceutical assistance (selection, programming, acquisition, storage, distribution, and dispensing) by preventing the waste of medicines, which are an important resource and of considerable cost for health systems, thus enabling the allocation of health resources to better meet the needs of the population, assuring the availability of necessary pharmaceutical products in adequate quantity and quality to meet the demands of prescribed treatments [78-80].

However, it is important to highlight that several factors hinder the development and implementation of strategies that can improve infection protection and prevention services, especially concerning the diagnosis of co-infections and secondary infections, It is important to emphasize the development of new sensitive and accurate diagnostic tools, whose results may be obtained quickly, and therefore contributing to the choice of the most appropriate treatment [77], while also providing support for their availability to the population through the management and clinical pharmaceutical services provided to other health professionals, as well as patients in conditions of conducting the pharmacological treatments on their own [81].

Table 1: Bacterial pathogens and type pf infection reported in cases of co-infection and secondary infection in COVID-19

Reported pathogen	Infection	Reference
Alcaligenaceae family		
Achromobacter spp	INA	[82]
Bordetella bronchiseptica	Respiratory infection	[83]
Bordetella pertussis	Bacteremia and respiratory infection in children	[34, 84-86]
Actinomycetaceae family		
Actinomyces spp	INA	[44]
Bacteriodaceae family		
Bacteroides spp	INA	[53]
Burkholderiaceae family		
Burkholderia cepacia	Bacteremia	[36]
Lautropia sp	INA	[59]
Brucellaceae family		
Brucella spp	Bacteremia	[87]
Chlamydiaceae family		
Chlamydia spp	Bacteremia and respiratory infection	[84]
Chlamydia pneumoniae	Bacteremia and respiratory infection	[11, 34, 88-90]
Clostridiaceae family		
Clostridioides difficile	Gastrointestinal infection	[54, 55]
Enterobacteriaceae family		
Citrobacter koseri	Urinary tract infection in a newborn	[52]
Escherichia coli	Bacteremia and respiratory infection	[34–37, 39, 42, 44, 56, 57, 82, 89, 91–96]
Enterobacter spp	Bacteremia and respiratory infection	[11, 35, 36, 95]
Enterobacter aerogenes	Respiratory infection	[56]
Enterobacter cloacae	Bacteremia, respiratory and soft tissue infection	[37, 39, 42, 53, 59, 91, 97]
Halfnia spp	INA	[35, 91]
Halfnia alvei	Bacteremia	[37]
Klebsiella spp	Bacteremia and respiratory infection	[84, 95]
Klebsiella aerogenes	Bacteremia and respiratory infection	[39, 44, 57]
Klebsiella oxytoca	Respiratory infection	[57, 85, 96]
Klebsiella pneumoniae	Bacteremia, respiratory and soft tissue infection	[11, 34–37, 39, 42–44, 53, 56, 59, 82, 91, 92, 94, 97–99]
Klebsiella variicola	INA	[96]
Morganella spp	INA	[91]
Proteus mirabilis	Bacteremia	[36, 100]
Providencia spp	INA	[91]
Serratia spp	INA	[35]
Serratia marcescens	Bacteremia	[53, 56]
Enterococcaceae family		
Enterococcus spp	Respiratory infection	[35, 36, 44, 56, 91]
Enterococcus casseliflavus	INA	[39]
Enterococcus faecium	Bacteremia, respiratory and urinary infection	[11, 39, 43, 53, 93, 94, 96]
Enterococcus faecalis	Bacteremia, cellulitis, respiratory and urinary tract infection	[36, 39, 42, 53, 57, 91]
Leionellaceae family		
Legionella spp	Bacteremia and respiratory infection	[84]
Legionella pneumophilia	Bacteremia and respiratory infection	[59, 84, 89, 96–98, 101, 102]
Moraxelaceae family		
Acinetobacter spp	Bacteremia	[36]
Acinetobacter baumannii	Bacteremia, respiratory and urinary infection	[11, 37, 40, 42, 44, 53, 56, 59, 93, 94, 97, 101]
Moraxella catarrhalis	INA	[34, 35, 37, 85, 92, 99]
Mycobacteriaceae family		
Mycobacterium abscessus	Respiratory infection	[103]
Mycobacterium bovis	Respiratory infection and extrapulmonary tuberculosis	[104, 105]
Mycobacterium leprae	Skin and peripheral nervous system infection	[51]
Mycobacterium tuberculosis	Respiratory infection and central nervous system infection	[50, 105-108]
Mycoplamataceae family		
Mycoplasma sp	Bacteremia	[84]
Mycoplasma pneumoniae	Bacteremia and respiratory infection	[11, 18, 34, 41, 59, 85, 88–90, 101, 119–123]
Neisseriaceae family		
Neisseria meningitidis	Infection of the central nervous system	[49, 85]
Pasteurallaceae family		
Haemophilus spp	INA	[59]
Haemophilus influenzae	Respiratory infection	[11, 35, 37, 44, 82, 85, 89, 92, 119]
Haemophilus parainfluenza	Respiratory infection	[82, 84]
Propinibacteriaceae family		
Cutibacterium spp	INA	[44]

Provetellaceae family		
Provetella spp	INA	[124]
Pseudomonadaceae family		
Pseudomonas spp	Bacteremia	[35]
Pseudomonas aeruginosa	Bacteremia and respiratory infection	[11, 34–37, 39, 42–44, 53, 56, 57, 85, 89, 91–95, 101, 119]
Pseudomonas putida	INA	[37]
Staphylococcaceae family		
Staphylococcus aureus	Bacteremia, Cellulite, Endocarditis, Respiratory infection	[11, 34–37, 40, 42, 43, 53, 56, 57, 82, 85, 89, 91, 92, 95, 96, 98–101]
Staphylococcus coagulase negative	Bacteremia	[43, 53]
Staphylococcus epidermidis	Bacteremia	[36, 94, 96]
Staphylococcus haemolytics	Bacteremia	[93, 94]
Staphylococcus hominis	Bacteremia	[94]
Streptococcaceae family		
Streptococcus spp	Bacteremia	[36, 44, 56]
Streptococcus salivarius	Bacteremia	[57]
Streptococcus group A	Bacteremia and respiratory infection	[125]
Streptococcus pneumoniae	Bacteremia and respiratory infection	[34, 35, 37, 42, 46, 59, 82, 85, 89, 92, 95, 96, 101, 126–128]
Streptococcus pyogenes	Bacteremia	[85]
Veillonellaceae family		
Veillonella spp	INA	[124]
Xanthomonadaceae family		
Stenotrophomonas spp	Bacteremia and respiratory infection	[36]
Stenotrophomonas maltophilia	Bacteremia and respiratory infection	[39, 53, 82, 91, 93, 94]

Final considerations

Co-infections and secondary bacterial infections in COVID-19 are clinical complications that require meticulous medical evaluation to be diagnosed and treated with the right drug. Emphasizing the diagnosis can be challenging due to the diversity of bacterial pathogens and the different anatomical sites that can be infected.

In this context, this work presents valuable insights that can contribute to the identification of co-infections and secondary bacterial infections in COVID-19. However, it also presents limitations concerning the diversity of studies analyzed, ranging from clinical cases to retrospective studies and literature reviews, which in some cases did not allow the extraction of pieces of information such as the type of infection to which some pathogens are linked.

Nevertheless, the perspective presented on the phenomenon of bacterial co-infection/secondary in COVID-19 shows that diagnostic protocols for co-infections and secondary bacterial infections in COVID-19, antibiotic stewardship, as well as the development of faster diagnostic means, are necessary to improve clinical decision making to combat mortality involved in this problem.

Conflicts of interest

The authors declare that there are no conflicts of interest.

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References

1. Guan X, Tian Y, Song J, Zhu D, Shi L. Effect of physicians' knowledge on antibiotics rational use in China's county hospitals. Soc. Sci. Med 1982. 2019;224:149–155.
2. Nausheen S, Hammad R, Khan A. Rational use of antibiotics--a quality improvement initiative in hospital setting. JPMA J Pak Med Assoc. 2013;63(1):60–64.
3. Opalska A, Kwa M, Leufkens H, Gardarsdottir H. Enabling appropriate use of antibiotics: Review of European Union procedures of harmonising product information, 2007 to 2020. Euro Surveill Bull Eur Sur Mal Transm Eur Commun Dis Bull, 2020, 25(45).
4. Horwitz RI, Charlson ME, Singer BH. Medicine based evidence and personalized care of patients. Eur. J Clin. Invest. 2018;48(7):e12945.
5. Zaharias G. Narrative-based medicine and the general practice consultation: Narrative-based medicine 2. Can Fam Physician Med Fam Can. 2018;64(4):286–90.
6. Freddi G, Romàn-Pumar JL. Evidence-based medicine: what it can and cannot do. Ann Ist Super Sanita. 2011;47(1):22–25.
7. Cawcutt K, Kalil AC. Pneumonia with bacterial and viral co-infection. Curr. Opin. Crit. Care. Outubro de. 2017;23(5):385–390.
8. MacIntyre CR, Chughtai AA, Barnes M, Ridda I, Seale H, Toms R, *et al*. The role of pneumonia and secondary bacterial infection in fatal and serious outcomes of pandemic influenza a (H1N1) pdm 09. BMC Infect Dis. 2018;18(1):637.
9. Walaza S, Cohen C, Tempia S, Moyes J, Nguweneza A, Madhi SA, *et al*. Influenza and tuberculosis co-infection: A systematic review. Influenza Other Respir Viruses. 2020;14(1):77–91.
10. Lai CC, Wang CY, Hsueh PR. Co-infections among patients with COVID-19: The need for combination therapy with non-anti-SARS-CoV-2 agents? J Microbiol Immunol Infect Wei Mian Yu Gan Ran Za Zhi. 2020;53(4):505–512.
11. Lansbury L, Lim B, Baskaran V, Lim WS. Co-infections in people with COVID-19: A systematic review and meta-analysis. J Infect. 2020;81(2):266–75.
12. Wu CP, Adhi F, Highland K. Recognition and management of respiratory co-infection and secondary bacterial pneumonia in patients with COVID-19. Cleve Clin J Med. 2020;87(11):659–63.
13. Parrill A, Tsao T, Dong V, Huy NT. SARS-CoV-2-induced immune dysregulation and the need for higher

clinical suspicion for co-infection and secondary infection in COVID-19 patients. J Microbiol Immunol Infect Wei Mian Yu Gan Ran Za Zhi. 2021;54(1):105–8.
14. Peng X, Xu X, Li Y, Cheng L, Zhou X, Ren B. Transmission routes of 2019-nCoV and controls in dental practice. Int J Oral Sci. 2020;12(1):9.
15. Umakanthan S, Sahu P, Ranade AV, Bukelo MM, Rao JS, Abrahao-Machado LF, *et al*. Origin, transmission, diagnosis and management of coronavirus disease 2019 (COVID-19). Postgrad Med J. 2020;96(1142):753-8.
16. Mohamadian M, Chiti H, Shoghli A, Biglari S, Parsamanesh N, Esmaeilzadeh A, *et al*. COVID-19: Virology, biology and novel laboratory diagnosis. J Gene Med. 2021;23(2):e3303.
17. Luers JC, Rokohl AC, Loreck N, Wawer Matos PA, Augustin M, Dewald F, *et al*. Olfactory and Gustatory Dysfunction in Coronavirus Disease 2019 (COVID-19). Clin Infect Dis Off Publ. Infect Dis Soc. Am. 2020;71(16):2262–4.
18. Gao Z, Xu Y, Sun C, Wang X, Guo Y, Qiu S, *et al*. A systematic review of asymptomatic infections with COVID-19. J Microbiol Immunol Infect Wei Mian Yu Gan Ran Za Zhi. 2021;54(1):12–6.
19. Hou YJ, Okuda K, Edwards CE, Martinez DR, Asakura T, Dinnon KH, *et al*. SARS-CoV-2 Reverse Genetics Reveals a Variable Infection Gradient in the Respiratory Tract. Cell. 2020;182(2):429-446.e14.
20. Engin AB, Engin ED, Engin A. Two important controversial risk factors in SARS-CoV-2 infection: Obesity and smoking. Environ Toxicol Pharmacol. 2020;78:103411.
21. Wu Z, McGoogan JM. Characteristics of and Important Lessons From the Coronavirus Disease 2019 (COVID-19) Outbreak in China: Summary of a Report of 72 314 Cases From the Chinese Center for Disease Control and Prevention. JAMA. 2020;323(13):1239–42.
22. Katsura H, Sontake V, Tata A, Kobayashi Y, Edwards CE, Heaton BE, *et al*. Human Lung Stem Cell-Based Alveolospheres Provide Insights into SARS-CoV-2-Mediated Interferon Responses and Pneumocyte Dysfunction. Cell Stem Cell. 2020;27(6):890-904.e8.
23. Anka AU, Tahir MI, Abubakar SD, Alsabbagh M, Zian Z, Hamedifar H, *et al*. Coronavirus disease 2019 (COVID-19): An overview of the immunopathology, serological diagnosis and management. Scand J Immunol. 2021;93(4):e12998.
24. Morris G, Bortolasci CC, Puri BK, Olive L, Marx W, O'Neil A, *et al*. The pathophysiology of SARS-CoV-2: A suggested model and therapeutic approach. Life Sci. 2020;258:118166.
25. Wang F, Kream RM, Stefano GB. Long-Term Respiratory and Neurological Sequelae of COVID-19. Med Sci Monit Int Med J Exp Clin Res. 2020;26:e928996.
26. Denina M, Pruccoli G, Scolfaro C, Mignone F, Zoppo M, Giraudo I, *et al*. Sequelae of COVID-19 in Hospitalized Children: A 4-Months Follow-Up. Pediatr Infect Dis J. 2020;39(12):e458–9.
27. Huang C, Huang L, Wang Y, Li X, Ren L, Gu X, *et al*. 6-month consequences of COVID-19 in patients discharged from hospital: A cohort study. Lancet Lond Engl. 2021;397(10270):220–32.
28. McDonald LT. Healing after COVID-19: are survivors at risk for pulmonary fibrosis? Am J Physiol Lung Cell Mol Physiol. 2021;320(2):L257–65.
29. Ronco C, Reis T, Husain-Syed F. Management of acute kidney injury in patients with COVID-19. Lancet Respir Med. 2020;8(7):738–42.
30. Gabarre P, Dumas G, Dupont T, Darmon M, Azoulay E, Zafrani L. Acute kidney injury in critically ill patients with COVID-19. Intensive Care Med. 2020;46(7):1339–48.
31. Torres D de A, Ribeiro L do CB, Riello AP de FL, Horovitz DDG, Pinto LFR, Croda J. Reinfection of COVID-19 after 3 months with a distinct and more aggressive clinical presentation: Case report. J Med Virol. 2021;93(4):1857–9.
32. Hoang VT, Dao TL, Gautret P. Recurrence of positive SARS-CoV-2 in patients recovered from COVID-19. J Med Virol. 2020;92(11):2366–7.
33. Zhu F, Cao Y, Xu S, Zhou M. Co-infection of SARS-CoV-2 and HIV in a patient in Wuhan city, China. J Med Virol. 2020;92(6):529–30.
34. Zhu X, Ge Y, Wu T, Zhao K, Chen Y, Wu B, *et al*. Co-infection with respiratory pathogens among COVID-2019 cases. Virus Res. 2020;285:198005.
35. Elabbadi A, Turpin M, Gerotziafas GT, Teulier M, Voiriot G, Fartoukh M. Bacterial coinfection in critically ill COVID-19 patients with severe pneumonia. Infection. 2021;
36. Nori P, Cowman K, Chen V, Bartash R, Szymczak W, Madaline T, *et al*. Bacterial and fungal co-infections in COVID-19 patients hospitalized during the New York City pandemic surge. Infect Control Hosp Epidemiol. 2021;42(1):84–8.
37. Contou D, Claudinon A, Pajot O, Micaëlo M, Longuet Flandre P, Dubert M, *et al*. Bacterial and viral co-infections in patients with severe SARS-CoV-2 pneumonia admitted to a French ICU. Ann Intensive Care. 2020;10(1):119.
38. Goncalves Mendes Neto A, Lo KB, Wattoo A, Salacup G, Pelayo J, DeJoy R, *et al*. Bacterial infections and patterns of antibiotic use in patients with COVID-19. J Med Virol; c2020.
39. Cataldo MA, Tetaj N, Selleri M, Marchioni L, Capone A, Caraffa E, *et al*. Incidence of bacterial and fungal bloodstream infections in COVID-19 patients in intensive care: An alarming "collateral effect". J Glob Antimicrob Resist. 2020;23:290–1.
40. Sharifipour E, Shams S, Esmkhani M, Khodadadi J, Fotouhi-Ardakani R, Koohpaei A, *et al*. Evaluation of bacterial co-infections of the respiratory tract in COVID-19 patients admitted to ICU. BMC Infect Dis. 2020;20(1):646.
41. Gayam V, Konala VM, Naramala S, Garlapati PR, Merghani MA, Regmi N, *et al*. Presenting characteristics, comorbidities, and outcomes of patients co-infected with COVID-19 and Mycoplasma pneumoniae in the USA. J Med Virol. 2020;92(10):2181–7.
42. Ramadan HK-A, Mahmoud MA, Aburahma MZ, Elkhawaga AA, El-Mokhtar MA, Sayed IM, *et al*. Predictors of Severity and Co-Infection Resistance Profile in COVID-19 Patients: First Report from Upper Egypt. Infect Drug Resist. 2020;13:3409–22.
43. Montrucchio G, Corcione S, Sales G, Curtoni A, De Rosa FG, Brazzi L. Carbapenem-resistant Klebsiella

pneumoniae in ICU-admitted COVID-19 patients: Keep an eye on the ball. J Glob Antimicrob Resist. 2020;23:398–400.
44. Chen X, Liao B, Cheng L, Peng X, Xu X, Li Y, *et al*. The microbial co-infection in COVID-19. Appl Microbiol Biotechnol. 2020;104(18):7777–85.
45. Wu Q, Xing Y, Shi L, Li W, Gao Y, Pan S, *et al*. Coinfection and Other Clinical Characteristics of COVID-19 in Children. Pediatrics, 2020, 146(1).
46. Cucchiari D, Pericàs JM, Riera J, Gumucio R, Md EC, Nicolás D, *et al*. Pneumococcal super-infection in COVID-19 patients: A series of 5 cases. Med Clin (Barc). 2020;155(11):502–5.
47. Amaral LTW, Beraldo GL, Brito VM, Rosa MEE, Matos MJR de, Fonseca EKUN, *et al*. Lung cavitation in COVID-19: co-infection complication or rare evolution? Einstein Sao Paulo Braz. 2020;18:eAI5822.
48. Rodriguez-Nava G, Yanez-Bello MA, Trelles-Garcia DP, Chung CW, Egoryan G, Friedman HJ. A Retrospective Study of Coinfection of SARS-CoV-2 and Streptococcus pneumoniae in 11 Hospitalized Patients with Severe COVID-19 Pneumonia at a Single Center. Medical Science Monitor International Medical Journal of Experimental and Clinical Research. 2020;26:e928754.
49. Gallacher SD, Seaton A. Meningococcal meningitis and COVID-19 co-infection. BMJ Case Rep, 2020, 13(8).
50. Freij BJ, Gebara BM, Tariq R, Wang A-M, Gibson J, El-Wiher N, *et al*. Fatal central nervous system co-infection with SARS-CoV-2 and tuberculosis in a healthy child. BMC Pediatr. 2020;20(1):429.
51. Schmitz V, Dos Santos JB. COVID-19, leprosy, and neutrophils. PLoS Negl Trop Dis. 2021;15(1):e0009019.
52. Tchidjou HK, Romeo B. Infant Case of Co-infection with SARS-CoV-2 and *Citrobacter koseri* Urinary Infection. J Trop Pediatr; c2020.
53. Bardi T, Pintado V, Gomez-Rojo M, Escudero-Sanchez R, Azzam Lopez A, Diez-Remesal Y, *et al*. Nosocomial infections associated to COVID-19 in the intensive care unit: clinical characteristics and outcome. Eur J Clin Microbiol Infect Dis off Publ Eur Soc Clin Microbiol; c2021.
54. Oba J, Silva CA, Toma RK, Carvalho WB de, Delgado AF. COVID-19 and co-infection with Clostridioides (Clostridium) difficile in an infant with gastrointestinal manifestation. Einstein Sao Paulo Braz. 2020;18:eRC6048.
55. Sandhu A, Tillotson G, Polistico J, Salimnia H, Cranis M, Moshos J, *et al*. *Clostridioides difficile* in COVID-19 Patients, Detroit, Michigan, USA, March-April 2020. Emerg Infect Dis., 2020, 26(9).
56. Antinori S, Galimberti L, Milazzo L, Ridolfo AL. Bacterial and fungal infections among patients with SARS-CoV-2 pneumonia. Infez Med. 2020;28(1):29–36.
57. Townsend L, Hughes G, Kerr C, Kelly M, O'Connor R, Sweeney E, *et al*. Bacterial pneumonia coinfection and antimicrobial therapy duration in SARS-CoV-2 (COVID-19) infection. JAC-Antimicrob Resist. 2020;2(3):dlaa071.
58. Rodríguez-Álvarez M, López-Vidal Y, Soto-Hernández JL, Miranda-Novales MG, Flores-Moreno K, Ponce de León-Rosales S. COVID-19: Clouds Over the Antimicrobial Resistance Landscape. Arch Med Res. 2021;52(1):123–6.
59. Mirzaei R, Goodarzi P, Asadi M, Soltani A, Aljanabi HAA, Jeda AS, *et al*. Bacterial co-infections with SARS-CoV-2. IUBMB Life. 2020;72(10):2097–111.
60. Adeiza SS, Shuaibu AB, Shuaibu GM. Random effects meta-analysis of COVID-19/S. aureus partnership in co-infection. GMS Hyg Infect Control. 2020;15:Doc29.
61. Brauner A, Fridman O, Gefen O, Balaban NQ. Distinguishing between resistance, tolerance and persistence to antibiotic treatment. Nat Rev Microbiol. 2016;14(5):320–30.
62. Abisado RG, Benomar S, Klaus JR, Dandekar AA, Chandler JR. Bacterial Quorum Sensing and Microbial Community Interactions. Bio, 2018, 9(3).
63. Tenover FC. Mechanisms of antimicrobial resistance in bacteria. Am J Med. 2006;119(6-1):S3-10. Discussion S62-70.
64. Wei X, You L, Wang D, Huang H, Li S, Wang D. Antimicrobial resistance and molecular genotyping of Salmonella enterica serovar Enteritidis clinical isolates from Guizhou province of Southwestern China. PloS One. 2019;14(9):e0221492.
65. Chen Z, Liu M, Cui Y, Wang L, Zhang Y, Qiu J, *et al*. A novel PCR-based genotyping scheme for clinical Klebsiella pneumoniae. Future Microbiol. 2014;9(1):21–32.
66. Raphael BH, Huynh T, Brown E, Smith JC, Ruberto I, Getsinger L, *et al*. Culture of Clinical Specimens Reveals Extensive Diversity of Legionella pneumophila Strains in Arizona. mSphere, 2019, 4(1).
67. Reyna-Fabián ME, Zermeño V, Ximénez C, Flores J, Romero MF, Diaz D, *et al*. Analysis of the Bacterial Diversity in Liver Abscess: Differences between Pyogenic and Amebic Abscesses. Am J Trop Med Hyg. 2016;94(1):147–55.
68. Thabit AK, Fatani DF, Bamakhrama MS, Barnawi OA, Basudan LO, Alhejaili SF. Antibiotic penetration into bone and joints: An updated review. Int J Infect Dis IJID Off Publ Int Soc Infect Dis. 2019;81:128–36.
69. Meng L, Mui E, Holubar MK, Deresinski SC. Comprehensive Guidance for Antibiotic Dosing in Obese Adults. Pharmacotherapy. 2017;37(11):1415–31.
70. Nau R, Seele J, Djukic M, Eiffert H. Pharmacokinetics and pharmacodynamics of antibiotics in central nervous system infections. Curr Opin Infect Dis. 2018;31(1):57–68.
71. Pea F. Pharmacokinetics and drug metabolism of antibiotics in the elderly. Expert Opin Drug Metab Toxicol. 2018;14(10):1087–100.
72. Yılmaz Ç, Özcengiz G. Antibiotics: Pharmacokinetics, toxicity, resistance and multidrug efflux pumps. Biochem Pharmacol. 2017;133:43–62.
73. Gualandi R, Masella C, Viglione D, Tartaglini D. Exploring the hospital patient journey: What does the patient experience? PloS One. 2019;14(12):e0224899.
74. Granström A, Strömmer L, Falk A-C, Schandl A. Patient experiences of initial trauma care. Int Emerg Nurs. 2019;42:25–9.
75. Nieuwlaat R, Mbuagbaw L, Mertz D, Burrows L, Bowdish DME, Moja L, *et al*. COVID-19 and Antimicrobial Resistance: Parallel and Interacting Health Emergencies. Clin Infect Dis Off Publ Infect Dis Soc Am. 2020;

76. Rawson TM, Moore LSP, Castro-Sanchez E, Charani E, Davies F, Satta G, *et al*. COVID-19 and the potential long-term impact on antimicrobial resistance. J Antimicrob Chemother. 2020;75(7):1681–4.
77. Cantón R, Gijón D, Ruiz-Garbajosa P. Antimicrobial resistance in ICUs: an update in the light of the COVID-19 pandemic. Curr Opin Crit Care. 2020;26(5):433–41.
78. Felder TM, Palmer NR, Lal LS, Mullen PD. What is the evidence for pharmaceutical patient assistance programs? A systematic review. J Health Care Poor Underserved. 2011;22(1):24–49.
79. Chukwu OA, Ezeanochikwa VN, Eya BE. Supply chain management of health commodities for reducing global disease burden. Res Soc Adm Pharm RSAP. 2017;13(4):871–4.
80. Duong MH, Moles RJ, Chaar B, Chen TF. Stakeholder roles in facilitating access to essential medicines. Res Soc Adm Pharm RSAP. 2019;15(3):260–6.
81. Santos FTC, Silva DLM da, Tavares NUL, Santos FTC, Silva DLM da, Tavares NUL. Pharmaceutical clinical services in basic care in a region of the municipality of São Paulo. Braz J Pharm Sci, 2018, 54(3).
82. Karami Z, Knoop BT, Dofferhoff ASM, Blaauw MJT, Janssen NA, van Apeldoorn M, *et al*. Few bacterial co-infections but frequent empiric antibiotic use in the early phase of hospitalized patients with COVID-19: results from a multicentre retrospective cohort study in The Netherlands. Infect Dis Lond Engl. 2021;53(2):102–10.
83. Faqihi F, Alharthy A, Pirompanich P, Noor A, Shahzad A, Nasim N, *et al*. Co-infection of SARS-CoV-2 and *Bordetella bronchiseptica* in a young man with idiopathic non-cystic bronchiectasis and vitamin D3 deficiency. Respir Med Case Rep. 2020;31:101203.
84. Davis B, Rothrock AN, Swetland S, Andris H, Davis P, Rothrock SG. Viral and atypical respiratory co-infections in COVID-19: a systematic review and meta-analysis. J Am Coll Emerg Physicians Open. 2020;
85. He F, Xia X, Nie D, Yang H, Jiang Y, Huo X, *et al*. Respiratory bacterial pathogen spectrum among COVID-19 infected and non-COVID-19 virus infected pneumonia patients. Diagn Microbiol Infect Dis. 2020;98(4):115199.
86. Rossetti E, Appierto L, Meschini A, Leone G, Lazzaro S, Del Principe G, *et al*. Early Leukapheresis Depletion in an Ex-Premature with Severe Acute Respiratory Distress Syndrome Due to *Bordetella Pertussis* and Coronavirus Infection. Blood Purif. 2020;49(6):758–60.
87. Elzein F, Alsherbeeni N, Almatrafi K, Shosha D, Naoufel K. COVID-19 co-infection in a patient with brucella bacteremia. Respir Med Case Rep. 2020;31:101183.
88. Oliva A, Siccardi G, Migliarini A, Cancelli F, Carnevalini M, D'Andria M, *et al*. Co-infection of SARS-CoV-2 with Chlamydia or Mycoplasma pneumoniae: a case series and review of the literature. Infection. 2020;48(6):871–7.
89. Sharov KS. SARS-CoV-2-related pneumonia cases in pneumonia picture in Russia in March-May 2020: Secondary bacterial pneumonia and viral co-infections. J Glob Health. 2020;10(2):020504.
90. Ma L, Wang W, Le Grange JM, Wang X, Du S, Li C, *et al*. Coinfection of SARS-CoV-2 and Other Respiratory Pathogens. Infect Drug Resist. 2020;13:3045–53.
91. Hughes S, Troise O, Donaldson H, Mughal N, Moore LSP. Bacterial and fungal co-infection among hospitalized patients with COVID-19: A retrospective cohort study in a UK secondary-care setting. Clin Microbiol Infect Off Publ Eur Soc Clin Microbiol Infect Dis. 2020;26(10):1395–9.
92. Garcia-Vidal C, Sanjuan G, Moreno-García E, Puerta-Alcalde P, Garcia-Pouton N, Chumbita M, *et al*. Incidence of co-infections and superinfections in hospitalized patients with COVID-19: a retrospective cohort study. Clin Microbiol Infect Off Publ Eur Soc Clin Microbiol Infect Dis. 2021;27(1):83–8.
93. Lv Z, Cheng S, Le J, Huang J, Feng L, Zhang B, *et al*. Clinical characteristics and co-infections of 354 hospitalized patients with COVID-19 in Wuhan, China: a retrospective cohort study. Microbes Infect. 2020;22(4–5):195–159.
94. Li J, Wang J, Yang Y, Cai P, Cao J, Cai X, *et al*. Etiology and antimicrobial resistance of secondary bacterial infections in patients hospitalized with COVID-19 in Wuhan, China: a retrospective analysis. Antimicrob Resist Infect Control. 2020;9(1):153.
95. Mahmoudi H. Bacterial co-infections and antibiotic resistance in patients with COVID-19. GMS Hyg Infect Control. 2020;15:Doc35.
96. Rothe K, Feihl S, Schneider J, Wallnöfer F, Wurst M, Lukas M, *et al*. Rates of bacterial co-infections and antimicrobial use in COVID-19 patients: a retrospective cohort study in light of antibiotic stewardship. Eur J Clin Microbiol Infect Dis Off Publ Eur Soc Clin Microbiol; c2020.
97. Rawson TM, Moore LSP, Zhu N, Ranganathan N, Skolimowska K, Gilchrist M, *et al*. Bacterial and Fungal Coinfection in Individuals With Coronavirus: A Rapid Review To Support COVID-19 Antimicrobial Prescribing. Clin Infect Dis Off Publ Infect Dis Soc Am. 2020;71(9):2459–2468.
98. Cheng LS-K, Chau SK-Y, Tso EY-K, Tsang SW-C, Li IY-F, Wong BK-C, *et al*. Bacterial co-infections and antibiotic prescribing practice in adults with COVID-19: experience from a single hospital cluster. Ther Adv Infect Dis. 2020;7:2049936120978095.
99. Massey BW, Jayathilake K, Meltzer HY. Respiratory Microbial Co-infection With SARS-CoV-2. Front Microbiol. 2020;11:2079.
100. Lehmann CJ, Pho MT, Pitrak D, Ridgway JP, Pettit NN. Community Acquired Co-infection in COVID-19: A Retrospective Observational Experience. Clin Infect Dis Off Publ Infect Dis Soc Am; c2020.
101. Prasetyoputri A. Detection of Bacterial Coinfection in COVID-19 Patients Is a Missing Piece of the Puzzle in the COVID-19 Management in Indonesia. ACS Infect Dis. 27 de janeiro de; c2021.
102. Arashiro T, Nakamura S, Asami T, Mikuni H, Fujiwara E, Sakamoto S, *et al*. SARS-CoV-2 and Legionella co-infection in a person returning from a Nile cruise. J Travel Med, 2020, 27(3).
103. Rodriguez JA, Bonnano C, Khatiwada P, Roa AA, Mayer D, Eckardt PA, *et al*. COVID-19 Coinfection with Mycobacterium abscessus in a Patient with Multiple Myeloma. Case Rep Infect Dis. 2021;2021:8840536.
104. Motta I, Centis R, D'Ambrosio L, García-García JM,

Goletti D, Gualano G, *et al*. Tuberculosis, COVID-19 and migrants: Preliminary analysis of deaths occurring in 69 patients from two cohorts. Pulmonology. 2020;26(4):233–40.
105. Singh A, Prasad R, Gupta A, Das K, Gupta N. Severe acute respiratory syndrome coronavirus-2 and pulmonary tuberculosis: convergence can be fatal. Monaldi Arch Chest Dis Arch Monaldi Mal Torace, 2020, 90(3).
106. Tham SM, Lim WY, Lee CK, Loh J, Premkumar A, Yan B, *et al*. Four Patients with COVID-19 and Tuberculosis, Singapore, April-May 2020. Emerg Infect Dis. 2020;26(11):2764–2766.
107. Vilbrun SC, Mathurin L, Pape JW, Fitzgerald D, Walsh KF. Case Report: Multidrug-Resistant Tuberculosis and COVID-19 Coinfection in Port-au-Prince, Haiti. Am J Trop Med Hyg. 2020;103(5):1986–1988.
108. Yadav S, Rawal G. The case of pulmonary tuberculosis with COVID-19 in an Indian male-a first of its type case ever reported from South Asia. Pan Afr Med J. 2020;36:374.
109. Yang H, Lu S. COVID-19 and Tuberculosis. J Transl Intern Med. 2020;8(2):59–65.
110. Yao Z, Chen J, Wang Q, Liu W, Zhang Q, Nan J, *et al*. Three Patients with COVID-19 and Pulmonary Tuberculosis, Wuhan, China, January-February 2020. Emerg Infect Dis. 2020;26(11):2755–2758.
111. Yousaf Z, Khan AA, Chaudhary HA, Mushtaq K, Parengal J, Aboukamar M, *et al*. Cavitary pulmonary tuberculosis with COVID-19 coinfection. IDCases. 2020;22:e00973.
112. Can Sarınoğlu R, Sili U, Eryuksel E, Olgun Yildizeli S, Cimsit C, Karahasan Yagci A. Tuberculosis and COVID-19: An overlapping situation during pandemic. J Infect Dev Ctries. 2020;14(7):721–725.
113. Essajee F, Solomons R, Goussard P, Van Toorn R. Child with tuberculous meningitis and COVID-19 coinfection complicated by extensive cerebral sinus venous thrombosis. BMJ Case Rep, 2020, 13(9).
114. Fattorini L, Creti R, Palma C, Pantosti A, Unit of Antibiotic Resistance and Special Pathogens, Unit of Antibiotic Resistance and Special Pathogens of the Department of Infectious Diseases, Istituto Superiore di Sanità, Rome. Bacterial co-infections in COVID-19: an underestimated adversary. Ann Ist Super Sanita. 2020;56(3):359–364.
115. Gadelha Farias LAB, Gomes Moreira AL, Austregésilo Corrêa E, Landim de Oliveira Lima CA, Lopes IMP, de Holanda PEL, *et al*. Case Report: Coronavirus Disease and Pulmonary Tuberculosis in Patients with Human Immunodeficiency Virus: Report of Two Cases. Am J Trop Med Hyg. 2020;103(4):1593–1596.
116. Martínez Orozco JA, Sánchez Tinajero Á, Becerril Vargas E, Delgado Cueva AI, Reséndiz Escobar H, Vázquez Alcocer E, *et al*. COVID-19 and Tuberculosis Coinfection in a 51-Year-Old Taxi Driver in Mexico City. Am J Case Rep. 2020;21:e927628.
117. Mousquer GT, Peres A, Fiegenbaum M. Pathology of TB/COVID-19 Co-Infection: The phantom menace. Tuberc Edinb Scotl. 2020;126:102020.
118. Rivas N, Espinoza M, Loban A, Luque O, Jurado J, Henry-Hurtado N, *et al*. Case Report: COVID-19 Recovery from Triple Infection with Mycobacterium tuberculosis, HIV, and SARS-CoV-2. Am J Trop Med Hyg. 2020;103(4):1597–9.
119. Langford BJ, So M, Raybardhan S, Leung V, Westwood D, MacFadden DR, *et al*. Bacterial co-infection and secondary infection in patients with COVID-19: a living rapid review and meta-analysis. Clin. Microbiol. Infect Off Publ. Eur. Soc. Clin. Microbiol. Infect. Dis. 2020;26(12):1622–9.
120. Amin D, McKitish K, Shah PS. Association of mortality and recent Mycoplasma pneumoniae infection in COVID-19 patients. J Med Virol. 2021;93(2):1180–3.
121. Huang J, Xie N, Hu X, Yan H, Ding J, Liu P, *et al*. Epidemiological, virological and serological features of COVID-19 cases in people living with HIV in Wuhan City: A population-based cohort study. Clin. Infect Dis off Publ Infect Dis Soc Am; c2020.
122. Tang ML, Li YQ, Chen X, Lin H, Jiang ZC, Gu DL, *et al*. Co-Infection with Common Respiratory Pathogens and SARS-CoV-2 in Patients with COVID-19 Pneumonia and Laboratory Biochemistry Findings: A Retrospective Cross-Sectional Study of 78 Patients from a Single Center in China. Med Sci. Monit. Int. Med J Exp Clin Res. 2021;27:e929783.
123. Wu CP, Adhi F, Highland K. Recognition and management of respiratory co-infection and secondary bacterial pneumonia in patients with COVID-19. Cleve Clin J Med. 2020;87(11):659–663.
124. Bao L, Zhang C, Dong J, Zhao L, Li Y, Sun J. Oral Microbiome and SARS-CoV-2: Beware of Lung Co-infection. Front Microbiol. 2020;11:1840.
125. Khaddour K, Sikora A, Tahir N, Nepomuceno D, Huang T. Case Report: The Importance of Novel Coronavirus Disease (COVID-19) and Coinfection with Other Respiratory Pathogens in the Current Pandemic. Am J Trop Med Hyg. 2020;102(6):1208–1209.
126. Pal C, Przydzial P, Chika-Nwosuh O, Shah S, Patel P, Madan N. Streptococcus pneumoniae Coinfection in COVID-19: A Series of Three Cases. Case Rep Pulmonol. 2020;2020:8849068.
127. Sohal S, Rodriguez-Nava G, Khabbaz R, Chaudry S, Musurakis C, Chitrakar S, *et al*. SARS-CoV2 and Co-Infections: A Review of Two Cases. Case Rep Infect Dis. 2020;2020:8882348.
128. Tsukamoto T, Nakajima N, Sakurai A, Nakajima M, Sakurai E, Sato Y, *et al*. Lung Pathology of Mutually Exclusive Co-infection with SARS-CoV-2 and Streptococcus pneumoniae. Emerg. Infect Dis. 2021, 27(3).

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