



Black Fungus an Add on Epidemic to COVID-19 Pandemic

**Shilpi Tiwari^{a*≡}, Parimala Kulkarni^{a∞}, Shikha Mali^{a#},
Sanjana Bhargava^{a†}, Nandini Jaiswal^{a†} and Arathi Menon^{b†}**

^a Department of Pediatric and Preventive Dentistry, People's College of Dental Sciences & Research Centre, Bhopal, Madhya Pradesh, India.

^b Department of Public Health Dentistry, People's College of Dental Sciences & Research Centre, Bhopal, Madhya Pradesh, India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JPRI/2021/v33i57B34044

Open Peer Review History:

This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: <https://www.sdiarticle5.com/review-history/78245>

Review Article

Received 06 November 2021

Accepted 12 December 2021

Published 14 December 2021

ABSTRACT

COVID-19 patients have lower immunosuppressive CD4+ T and CD8+ T cells and henceforth patients in intensive care units (ICU) need mechanical ventilation, henceforward they stay in hospitals. These patients have been exposed to advances in fungal co-infections. COVID-19 patients progress towards mucormycosis a black fungal infection that is deadly leading to loss of sight and hearing and eventually death. This article discusses the clinical manifestations, risk factors and emphases on virulence traits and management of black fungus.

Keywords: Black fungus; Mucormycosis; COVID-19; Rhino-orbital Mucormycosis.

1. INTRODUCTION

COVID-19 pandemic is an outbreak of coronavirus disease that was first acknowledged

in December 2019. As the infection is asymptomatic and the severity of the disease leads to respiratory failure and death [1]. The most significant challenges increasing day by

[≡] Professor;

[∞] Professor and Head;

[#] Reader;

[†] Post-Graduate Student;

*Corresponding author: E-mail: shilpi.tiwari1@gmail.com;

day is patient's morbidity and mortality which is caused by secondary fungal or bacterial infections [2]. Candidiasis and pulmonary aspergillosis have been common fungal infections that were reported as superinfections in COVID-19 patients [2,3]. On the other hand, it has been presumed that the oral manifestations which have been reported in association with (COVID-19) has the primary pathway for infection, precisely the ones of fungal origin [1-3].

Mucormycosis or Zygomycosis, also entitled Phycomycosis, is an unusual, aggressive, invasive, speedily progressive, and life-threatening fungal infection. Triple strain corona virus is considerably high on patients those are in need of ICU advancing them to suffer from mucormycosis. Hence fatality rate is estimated to be high [2]. The infection they cause, mucormycosis "black fungus," can infect the sinuses and bones of the face and invade the brain or cause patients to lose an eye [4]. Generally, patients reported problems to the physicians not only breathless, feverish yet had pain and pressure behind their cheekbones and around their eyes. The black fungus has painted the country red in the second wave [5].

The epidemic of mucormycosis is yet another of the unpleasant surprises produced by the COVID pandemic following MIS-C, a severe inflammatory syndrome that seems to mostly affect children, and "long COVID," which is a complex of symptoms that continue to distress patients months after initial infection [6]. Mucormycosis is one of the violent fungal diseases that have attacked COVID patients, including a lethal yeast called "Candida Auris" and a spate of infections with *Aspergillus* fungi which is also known as CAPA (for COVID-associated pulmonary aspergillosis) [7].

Mucormycosis has been a centre of attention all around the globe. But there seems difference in species and effects on the human body differing from a developed country and developing nations [8]. In developed nations this disease is less common and seen only in patients with haematological malignancies (HM). The developing countries paint a different picture, it is common in patients with uncontrolled diabetes mellitus or trauma. In India, mucormycosis is seen in 14 out of 100000 patients. In Europe and US, it is seen in 0.01 per 100000 population [6-7].

As the maxillofacial region consists of rich vascularity due to its anatomy, therefore it is

more prone to the opportunistic infections [9]. Mucormycosis has the potential for virulence to escape the defense mechanism [10]. The attributable risk factors comprise uncontrolled diabetes mellitus, long-term steroid therapy, Acquired Immune Deficiency Syndrome (AIDS), haematological conditions like leukemia and lymphomas, renal failure [11]. In the body the mucormycosis infection can easily invade into the body through nose, breached skin surface and tooth extraction sockets. Primary infection spots include the skin, ears, gastrointestinal tract, and there could be disseminated forms involving multiple locations like pulmonary and rhino-orbito-cerebral [10] Contingent on the site of infection and underlying inclining factors, mortality rates may vary from 10% to 100% [12]. Here, we review the black fungus regarding mucormycosis in immunocompromised patients and uses the evidence to provide recommendations and management for black fungus treatment.

1.1 Search Strategy

Electronic databases were explored (PubMed, Embase, Scopus, Dentistry and Oral Science Source, and Google Scholar) to maximize the identification of relevant primary studies published over the last 1 year (September 2020 – July 2021). During the initial search, the following MeSH and keywords were employed: "Mucormycosis", "Rhino-orbital mucormycosis" and "Black fungus" written in the English language.

1.2 Data Collection Process

The necessary available information was extracted from each initially included article, through different case reports.

1.3 Microbiology

Mucormycosis is caused by fungi which belongs to the order Mucorales. These ubiquitous fungi reside in the soil and organic debris. They cultivate rapidly and sporulate quickly and abundantly. The only term mucormycosis arise from the "Mucoraceae" family of the Mucorales order, which is substituted commonly from the term zygomycosis which is the prime suspect for the mucormycosis infection in the human. *Rhizopus arrhizus* species is frequently encounter, but some other mucor species also includes are *Lichtheimia* species

(formerly known as *Absidia* species), and *Cunninghamella* species [13].

1.4 Virulence Traits

Mucoromycotina able to grow at 37⁰ C known as a thermotolerant but some of them proliferates even at higher temperatures. However, in 2012 Schwartz et al [14] concluded the different virulence potential but there is no association has been observed among the growth speed at host temperature.

The second, virulence factor is iron acquisition, which acts as a vital role for development and fungal cell growth, as it has three general mechanisms for the uptake of iron and which has been identified in fungi. It encompasses for the reduction of iron uptake, siderophore-sequestered iron uptake which has been facilitated by the siderophorepermease and acquiring iron from haem in the uptake system [15].

Fungal isolates such as *Rhizopus* and *Lichtheimia corymbifera* along with *Mucor* species were found in children in some cases [16]. Keeping the factors of Hematological malignancies, organ transplant, surgery, diabetes mellitus and underlying various medical conditions. The fungus targets the compromised medical conditions and attacks lungs, skin, soft tissues, sino orbital and rhino cerebral region. Mortality rate for such cases were more than 60%. In Children it was 15% with certain infection [13,14].

Recently, another factor, has been identified i.e; glucose regulated protein 78 (GRP78) which enables the invasion of the pathogen through endocytotic mechanism. One more aspect contributing to virulence of a pathogen is its ability to evade recognition and elimination by the host immune system [17].

2. EPIDEMIOLOGY

As a group, Mucoraceae represent the third most common cause of invasive fungal infection after *Candida* and *Aspergillus* species [18]. As increasing incidence of mucormycosis has been recommended by epidemiologic studies [19]. Numerous factors contribute in the increase, incidences for including antifungal prophylaxis by agents without *Mucor* mycosis activity [1].

Pandemic has rapidly spread to 212 countries and caused nearly 5 million laboratory-confirmed cases and more than 310,000 deaths globally [20].

COVID-19 patients always have immunosuppression with a decrease in CD4 +T and CD8 +T cells.³ Critically ill patients admitted to the intensive care unit (ICU) with more extended stays were more likely to develop fungal co-infections [4]. It is crucial to notice that COVID- 19 patients can develop fungal infections [18-19].

2.1 Risk Factors

The immune dysfunction or immunodeficiency primary risk factor for the invasive diseases. The primary immunodeficiency form is not characteristically accompanying with the mucormycosis infection [20]. The substantial risk factor is associated with the hematologic malignancy, as the presence of hematopoietic stem cell transplant or solid organ transplant recipient. Solid organ malignancy (without transplant) is not commonly associated with mucormycosis [21].

Diabetes also is a commonly identified risk factor, with 9% to 36% of cases occurring in diabetics [7–9]. In human monocytes, elevated glucose levels directly increase SARS-CoV-2 replication, and glycolysis sustains SARS-CoV-2 replication via the production of mitochondrial reactive oxygen species and activation of hypoxia-inducible factor 1 α 20. Therefore, hyperglycaemia might support viral proliferation. In concurrence with this assumption, hyperglycaemia or a history of T1DM and T2DM were found to be independent predictors of morbidity and mortality in patients with SARS [21].

Furthermore, comorbid T2DM in mice infected with MERS-CoV resulted in a dysregulated immune response, leading to severe and extensive lung pathology [22]. Patients with diabetes mellitus typically fall into higher categories of SARS-CoV-2 infection severity than those without [23,24], and poor glycaemic control predicts an increased need for medications and hospitalizations, and increased mortality [18,25].

Table 1. Summary of the COVID-19 associated mucormycosis (CAM) reported in the literature

Author/country	Age in years/ sex	Comorbid illness	Clinical presentation	Organs involved by CAM	Treatment for COVID-19	Investigations	Management	Outcome
Hanley et al./UK{33}	22/M	Hypothyroidism	COVID ARDS (mechanically ventilated) Pulmonary emboli	Lungs, Hilar lymph nodes	None mentioned	Lymphocyte count and serum creatinine, not provided	-	-
Werthman Ehrenreich/USA{34}	33/F	Hypertension, Asthma	Altered mentation, proptosis and rhino-orbital mucormycosis	Rhino-orbitocerebral	Remdesivir, plasma therapy	Lymphopenia (5.9%) Elevated serum creatinine (2.28 mg/dL) Mri brain at -	1 st - intravenous fluids, sodium bicarbonate insulin infusions. 2 nd - Vancomycin, piperacillin-tazobactam were administered Amphotericin B was added 3 rd - MRI brain, remdesivir convalescent plasma.	26 th day survival.
Mehta et al./India{35}	60/M	Diabetes mellitus Peripheral vascular disease due to diabetes	COVID ARDS requiring mechanical ventilation	Rhino-orbital	Inj methylprednisolone 40 mg BD Dexamethasone 4 mg BD Tocilizumab 400 mg	Elevated serum creatinine (1.57 mg/dL)	1 st - intravenous meropenem, oral oseltamivir, with intravenous methylprednisolone and dexamethasone. 2 nd - shifted to non-invasive ventilation to maintain his oxygen saturation 3 rd - received a single dose of injectable tocilizumab (400 mg) and was started on an oral combination of sitagliptin/metformin (50/500) twice daily and oral metformin (500 mg) thrice	6 th day Survival

Author/country	Age in years/sex	Comorbid illness	Clinical presentation	Organs involved by CAM	Treatment for COVID-19	Investigations	Management	Outcome
Monte junior ESD et al./Brazil{36}	86/M	Hypertension	COVID ARDS and diarrhea	Gastric (presentation with melena, drop in hemoglobin, and large ulcers identified on endoscopy)	Hydrocortisone	Lymphopenia (5.3%)	daily with subcutaneous insulin glargine (20 units) at night with regular insulin 1 st - treated with ceftriaxone, azithromycin, oseltamivir, and hydrocortisone, besides intensive care management including vasopressors and mechanical ventilation. 2 nd - managed with three units of red blood cells and omeprazole. 3 rd - Esophagogastroduodenoscopy (EGD) revealed two giant gastric ulcers. Antifungal agents were not administered.	1 week survival
Placik et al./USA{37}	49/M		COVID ARDS	Pulmonary mucormycosis with bronchopleural fistula and pneumothorax	Remdesivir Tocilizumab Dexamethasone	Lymphocyte count and serum creatinine, not provided	1 st - empiric antibiotics with ceftriaxone and azithromycin, low-weight-molecular heparin therapy with enoxaparin, a steroid course with dexamethasone, and antiviral therapy with remdesivir. 2 nd - started on a dose of tocilizumab, a humanized monoclonal antibody that	37 days survival

Author/country	Age in years/sex	Comorbid illness	Clinical presentation	Organs involved by CAM	Treatment for COVID-19	Investigations	Management	Outcome
Mekkonen et al./USA{38}	60/M	Diabetes mellitus (HbA1C 14%) Asthma Hypertension	COVID ARDS (mechanically ventilated)	Rhino-orbital	Remdesivir Dexamethasone (6 mg) Plasma therapy	NA	suppresses the interleukin-6 receptor. 3 rd - The patient was intubated for impending respiratory failure. 4 th - Initial cultures were concerning for a fungal process with probable mucormycosis. The patient was started on amphotericin B.	
Pasero et al./Italy {39}	66/M	Hypertension	COVID ARDS (mechanically ventilated)	Lung Maxillary sinus thickening on computed tomography (not proven to be mucormycosis)	Hydroxychloroquine Lopinavir-ritonavir	Lymphopenia (400/IL) Renal failure requiring dialysis (creatinine not provided)	1 st - A therapy with hydroxychloroquine and lopinavir-ritonavir was administered for the first 10 days. 2 nd -	62 days survival

ARDS: acute respiratory distress syndrome; BMI–body mass index; COVID: coronavirus disease; E.coli: Escherichia coli; HbA1c: glycated haemoglobin, F: female, M: male

2.2 Pathogenesis

These organisms are spread by air borne asexual spores and invade into the tissues in reduced host defences via respiratory tract, wounded skin or via transcutaneous route [25]. Due to its high affinity towards the plasma these fungal hyphae enter the arterial blood vessels of the internal elastic lamina and resulting into the thromboembolism and cause ensuing thrombotic infarction [26]. In the blood vessels they proliferate mainly in the lungs, paranasal sinuses and it leads to the infarction & necrosis of the blocked vessels towards the distal end of the tissue [21,22]. In the medically compromised patients like in diabetic patients the free iron level increases which enhances the growth of the these organisms [17].

2.3 Clinical Manifestations

This disease habitually presents with signs of acute sinusitis, fever, nasal congestion, purulent nasal discharge, and headache. Sinuses involvement with contiguous spread to adjacent structures such as the palate, orbit, brain results in clinical symptoms [27]. The disease spreads from the ethmoid sinus to the frontal lobe results in obtundation. Clinical suspicion and initial treatment with surgical debridement are vital in averting the morbidity of this often-fatal condition [28]. The clinical hallmark of mucormycosis is vascular invasion resulting in thrombosis and tissue infarction/necrosis. The most common clinical presentation of mucormycosis is a rhino-orbital cerebral infection [20-28]. It is believed to be secondary to inhalation of spores into the paranasal sinuses of a susceptible host. Predisposing mucormycosis factors are diabetes, systemic corticosteroid use, neutropenia, hematologic malignancies, stem cell transplant, and immunocompromised individuals.

Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infection resulting in tissue hypoxia, which persuades interstitial lung damage and acute respiratory distress syndrome [15-21]. Patients with diabetes mellitus and coronavirus disease 2019 (COVID-19) exhibits dysregulation of glucose homeostasis, exacerbation of inflammation and impairment in the function of the immune system. These conditions increase oxidative stress, cytokine production and endothelial dysfunction leading to increased risk of thromboembolism [12] and damage to vital organs. All these factors contribute to increased severity of COVID-19 and

rapid progression to cardiorespiratory failure in patients with diabetes mellitus.

- The grown research evidence demonstrated that saprophytic zygomycetes are rarely seen in the tissue of immune compromised patients. On the contrary, diabetes both type I and type II, tumor, and metabolic inflammation such fungal infections these chronic diseases significantly enhance the depletion of immunity. The fungal infection caused by *Rhizopus*, *mucor*, and *zygomycetes* primarily enter into blood vessels and trigger thrombosis as one of major hallmark of chronic fungal infections. The thrombosis cases are more common in para nasal sinus and lower respiratory tissue such as lungs causing ischemic cascade along with self -induce tissue damage.

2.4 Diagnosis

Mucormycosis in early diagnosis is critical which enables the early initiation of active antifungal therapy. The symptoms, signs and radiographic manifestations of mucormycosis are nonspecific and a definitive diagnosis requires direct identification of the characteristic hyphae or the recovery of organism in culture from specimens obtained from the site of infection. Specificity is also an issue, because isolation from nonsterile sites is sometimes indicative of contamination rather than disease. Culture of a clinically relevant isolate enables identification and susceptibility testing of the pathogen [16].

➤ Cytopathology

The hyphae may be difficult to observe on an unenhanced Potassium hydroxide wet mount and may not stain well with conventional Gram stain. The use of chitin binding stains, such as Calcoflour, Fungi-flour, or Blancoflour, may be used with a fluorescent microscope to identify hyphal elements on Potassium hydroxide wet mounts [24].

➤ Histopathology

The culture still forms the basis of diagnosis in most cases, although molecular techniques are being used increasingly to complement traditional methods [17]. Molecular testing improves the accuracy of species identification compared to phenotypic identification of culture

isolates [15]. Nucleic acid amplification techniques that target the ribosomal DNA gene targets 18S, 28S, and Internal Transcribed Spacer (ITS) region are all used. The sensitivity and specificity of molecular diagnosis performed directly on fresh or frozen tissue depend on the DNA-extraction method used [15]. Fresh material is preferred over paraffin-embedded tissue, because formalin damages DNA [16].

➤ Radiography/ Imaging Techniques

Computed tomography (CT) is useful in pre-operative procedure which defines the extent of the disease. Scan displays the edematous mucosa, fluid filling the sinuses and destruction of the peri-orbital tissue and bony margins, even though sinus CT is preferred in imaging modality, bony destruction is often existing in the course of the disease. Magnetic Resonance Imaging (MRI) is useful in identifying the intradural and intracranial extent of the disease, cavernous sinus thrombosis, or thrombosis of the cavernous portion of the internal carotid artery. Perineural spread of the disease can also be demonstrated with contrast enhanced MRI scan [26].

3. TREATMENT

Multimode approach is necessary to cure mucormycosis. Early dosage of anti-fungal agents, rapid correction of metabolic abnormalities are mandatory features. The global pandemic of COVID-19 has accelerated the race to find effective prevention and treatment for SARS-CoV-2 infection [27]. Currently, more than 1,800 clinical trials targeting viral entry and replication and immune responses to infection are ongoing; however, the efficacy of most drugs has not yet been proven (Clinical Trials. gov database of COVID-19 interventional studies) [28]. Candidates for COVID-19 therapy can affect glucose metabolism pharmacologically or through the modulation of inflammation and the immune system.

Thrombosis of blood vessel resulting in tissue necrosis during mucormycosis results in deprived penetration of antifungal agents to the site of infection. Therefore, the complete eradication of mucormycosis the debridement of necrotic tissues should be done [27]. Aggressive medical treatment with conventional antifungals and non-conventional therapeutics are corner stone for successful treatment [29]. Polyenes like Amphotericin-deoxycholates and lipid

complex are primary therapeutic agents for mucormycosis. The dosage varies from 0.5-1.0mg/kg body weight once daily for not less than 4 weeks [30]. There should be close monitoring of serum electrolytes, as polyenes are known to cause potassium imbalance [29,31]. Salvage therapy by Posaconazole or deferasirox are reasonable options for patient's refractory to or intolerant to polyene therapy [32]. Non-conventional therapeutic agents like anti-diabetics, iron chelating agents, statins, granulocyte transfusions, cytokines, and hyperbaric oxygen have increased the survival rates to 94%. Prevention always remains a gold standard [33].

Both medication and surgical management strategies are active in mucormycosis cases. Amphotericin B (liposomal) is the most frequently used drug in the management of mucormycosis [28-33]. Combination of liposomal amphotericin B and Posaconazole management manifests the synergistic effects against fungal hyphae formation [34-35]. Neutropenic patients or individuals with graft-versus-host disease should be indorsed for oral Posaconazole medication as prophylactic management against mucormycosis, although mucormycosis cases in neutropenia or graft-versus-host disease patients managed by oral administration of fluconazole, while itraconazole and voriconazole are administered as prophylactic doses [36-39].

4. CONCLUSION

The COVID-19 is accompanying with a significant incidence of secondary infections, both bacterial and fungal, perhaps due to deterioration of immunity. The key fragment for the treatment of COVID-19 is the widespread use of steroids/monoclonal antibodies/broad-spectrum antibiotics which exacerbates into the fungal diseases. The pre-existing factors gives a prospective of invasive secondary fungal infections in patients with COVID-19 infection. The early diagnosis and treatment of black fungus with rhino-orbital mucormycosis successively reduces the mortality and morbidity rates.

CONSENT

It is not applicable.

ETHICAL APPROVAL

It is not applicable.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

- Hughes S, Troise O, Donaldson H, et al. Bacterial and fungal coinfection among hospitalized patients with COVID19: a retrospective cohort study in a UK secondary-care setting [published online ahead of print, 2020 Jun 27]. *Clin Microbiol Infect.* 2020;26(10):1395–1399
- Richardson M, Lass-Flörl C. Changing epidemiology of systemic fungal infections. *Clinical microbiology and infection.* 2008;14(Suppl 4):5–24.
- Nagy E. Changing epidemiology of systemic fungal infections and the possibilities of laboratory diagnostics. *Acta microbiologica et immunologica Hungarica.* 1999;46(2-3):227–31.
- Clancy CJ, Schwartz IS, Kula B, Nguyen MH. Bacterial superinfections among persons with coronavirus disease 2019: A comprehensive review of data from postmortem studies. *Open Forum Infectious Diseases.* 2021;8(3):ofab065.
- Alanio A, Dellièrè S, Fodil S, Bretagne S, Mégarbane B. Prevalence of putative invasive pulmonary aspergillosis in critically ill patients with COVID-19. *The Lancet Respiratory Medicine* 2020;8(6): e48-e49.
- Pongas GN, Lewis RE, Samonis G, Kontoyiannis DP. Voriconazole-associated zygomycosis: a significant consequence of evolving antifungal prophylaxis and immunosuppression practices? *Clin Microbiol Infect.* 2009; 15(Suppl 5):93–7.
- Kontoyiannis DP, Lionakis MS, Lewis RE, et al. Zygomycosis in a tertiary-care cancer center in the era of Aspergillus-active antifungal therapy: a case-control observational study of 27 recent cases. *J Infect Dis* 2005;191:1350–60.
- Codo, A. C. et al. Elevated glucose levels favor SARS-CoV-2 infection and monocyte response through a HIF-1 α /glycolysis-dependent axis. *Cell Metab.* 32, 437–446.e5 (2020).
- Yang, J. K. et al. Plasma glucose levels and diabetes are independent predictors for mortality and morbidity in patients with SARS. *Diabet. Med.* 2006;23:623–628.
- Carey, I. M. et al. Risk of infection in type 1 and type 2 diabetes compared with the general population: a matched cohort study. *Diabetes Care.* 2018;41:513–521.
- Wu, C. et al. Risk factors associated with acute respiratory distress syndrome and death in patients with coronavirus disease 2019 pneumonia in Wuhan, China. *JAMA Intern. Med.* 180, 934–943 (2020).
- Critchley, J. A. et al. Glycemic control and risk of infections among people with type 1 or type 2 diabetes in a large primary care cohort study. *Diabetes Care* 41, 2127–2135 (2018).
- Zhu, L. et al. Association of blood glucose control and outcomes in patients with COVID-19 and preexisting type 2 diabetes. *Cell Metab.* 31, 1068–1077 (2020).
- Pongas GN, Lewis RE, Samonis G, Kontoyiannis DP. Voriconazole-associated zygomycosis: a significant consequence of evolving antifungal prophylaxis and immunosuppression practices? *Clin Microbiol Infect.* 2009; 15(Suppl 5):93–7.
- Kontoyiannis DP, Lionakis MS, Lewis RE, et al. Zygomycosis in a tertiary-care cancer center in the era of Aspergillus-active antifungal therapy: a case-control observational study of 27 recent cases. *J Infect Dis.* 2005; 191:1350–60
- Bravo D, Solano C, Giménez E, Remigia MJ, Corrales I, Amat P, Navarro D. Effect of the IL28B Rs12979860 C/T polymorphism on the incidence and features of active cytomegalovirus infection in allogeneic stem cell transplant patients. *Journal of Medical Virology.* 2014 May;86(5):838-44.
- Kubin CJ, Ellman TM, Phadke V, Haynes LJ, Calfee DP, Yin MT. Incidence and predictors of acute kidney injury associated with intravenous polymyxin B therapy. *Journal of Infection.* 2012 Jul 1; 65(1):80-7.
- Yang X, Yu Y, Xu J, Shu H, Liu H, Wu Y, Zhang L, Yu Z, Fang M, Yu T, Wang Y. Clinical course and outcomes of critically ill patients with SARS-CoV-2 pneumonia in Wuhan, China: a single centered

- retrospective, observational study. *The Lancet Respiratory Medicine*; 2020.
19. Gangneux JP, Bougnoux ME, Dannaoui E, Cornet M, Ralph ZJ. Invasive fungal diseases during COVID-19: We should be prepared. *Journal De Mycologie Medicale*. 2020 Apr 6.
 20. Schwartze VU, Hoffmann K, Nyilasi I, Papp T, Vágvölgyi C, d Hoog S, et al. Lichtheimia Species Exhibit Differences in Virulence Potential. *PLoS One*. 2012;7(7):e40908.
 21. Ibrahim AS, Spellberg B, Edwards J. Iron acquisition: a novel perspective on mucormycosis pathogenesis and treatment. *Curr Opin Infect Dis*. 2008;21(6):620–5.
 22. Binder U, Maurer E, Flörl CL. Mucormycosis – from the pathogens to the disease. *Clin Microbiol Infect*. 2014;20(6):60–6.
 23. Bitar D, Cauteren DV, Lanternier F, Dannaoui E, Cha D, Dromer F, et al. Increasing incidence of zygomycosis (Mucormycosis). *Emerg Infect Dis*. 1997;15(9):1395–401.
 24. Sun HY, Singh N. Mucormycosis: Its Contemporary Phase and Management Strategies. *Lancet Infect Dis*. 2011;11(4):301–11.
 25. Ibrahim AS, Spellberg B, Edwards J. Iron acquisition: a novel perspective on mucormycosis pathogenesis and treatment. *Curr Opin Infect Dis*. 2008;21(6):620–5.
 26. Ibrahim AS, Spellberg B, Walsh TJ, Kontoyiannis DP. *Cin Infect Dis*. 2012;54(1):S16–22.
 27. Lackner M, Caramalho R, Lass-Flörl C. Laboratory diagnosis of mucormycosis: current status and future perspectives. *Future Microbiol* 2014;9:683–95.
 28. Cornely OA, Arikian-Akdagli S, Dannaoui E, et al. ESCMID and ECMM joint clinical guidelines for the diagnosis and management of mucormycosis 2013. *Clin Microbiol Infect* 2014;20(Suppl 3):5–26.
 29. Millon L, Herbrecht R, Grenouillet F, et al; French Mycosis Study Group. Early diagnosis and monitoring of mucormycosis by detection of circulating DNA in serum: retrospective analysis of 44 cases collected through the French Surveillance Network of Invasive Fungal Infections (RESSIF). *Clin Microbiol Infect* 2016; 22:810.e1–8.
 30. Placik DA, Taylor WL, Wnuk NM. Bronchopleural fistula development in the setting of novel therapies for acute respiratory distress syndrome in SARS-CoV-2 pneumonia. *Radiol Case Rep*. 2020;15(11):2378–81
 31. Spellberg B, Ibrahim AS. Recent advances in the treatment of mucormycosis. *Curr Infect Dis Rep*. 2010;12(6):423–9.
 32. Morace G, Borghi E. Invasive mold infections: virulence and pathogenesis of mucorales. *International journal of microbiology*. 2011;2012.
 33. Cornely O, Arikian-Akdagli S, Dannaoui E, Groll A, Lagrou K, Chakrabarti A, et al. ESCMID† and ECMM‡ joint clinical guidelines for the diagnosis and management of mucormycosis 2013. *Clinical Microbiology and Infection*. 2014;20:5–26.
 34. Hanley B, Naresh KN, Roufousse C, Nicholson AG, Weir J, Cooke GS, et al. Histopathological findings and viral tropism in UK patients with severe fatal COVID-19: a postmortem study. *Lancet Microbe*. 2020;1(6):e245
 35. Pasero D, Sanna S, Liperi C, Piredda D, Branca GP, Casadio L, et al. A challenging complication following SARS-CoV2 infection: a case of pulmonary mucormycosis. *Infection*; 2020. Available: <https://doi.org/10.1007/s15010-020-01561-x>
 36. Werthman-Ehrenreich A. Mucormycosis with orbital compartment syndrome in a patient with COVID-19. *Am J Emerg Med*; 2020. Available:<https://doi.org/10.1016/j.ajem.2020.09.032>
 37. Mehta S, Pandey A. Rhino-orbital mucormycosis associated with COVID-19. *Cureus*. 2020;12(9):e10726.
 38. Monte Junior ESD, Santos M, Ribeiro IB, Luz GO, Baba ER, Hirsch BS, et al. Rare and fatal gastrointestinal mucormycosis (Zygomycosis) in a COVID-19 patient: a case report. *Clin Endosc*. 2020;53(6): 746–9.
 39. Mekonnen ZK, Ashraf DC, Jankowski T, Grob SR, Vagefi MR, Kersten RC, et al. Acute Invasive Rhino-Orbital

Mucormycosis in a Patient With COVID-19-Associated Acute Respiratory Distress Syndrome. Ophthalmic Plast Reconstr Surg; 2020.

Available:<https://doi.org/10.1097/IOP.0000000000001889>.

© 2021 Tiwari et al.; This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Peer-review history:

The peer review history for this paper can be accessed here:
<https://www.sdiarticle5.com/review-history/78245>