Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.
Original Article

Mucormycosis in COVID-19: A systematic review of cases reported worldwide and in India

Awadhesh Kumar Singh a,*, Ritu Singh a, Shashank R. Joshi b, Anoop Misra c,d,e

a Department of Diabetes & Endocrinology, G. D Hospital & Diabetes Institute, Kolkata, West Bengal, India
b Department of Diabetes & Endocrinology, Lilavati Hospital & Joshi Clinic, Mumbai, Maharashtra, India
c Fortis C-DOC Hospital for Diabetes & Allied Sciences, New Delhi, India
d National Diabetes, Obesity and Cholesterol Foundation, New Delhi, India
e Diabetes Foundation (India), New Delhi, India

Article info

Article history:
Received 14 May 2021
Accepted 15 May 2021

Keywords:
Mucormycosis
Diabetes mellitus
Corticosteroids
COVID-19
Systematic review

Abstract

Background and aims: There are increasing case reports of rhino-orbital mucormycosis in people with coronavirus disease 2019 (COVID-19), especially from India. Diabetes mellitus (DM) is an independent risk factor for both severe COVID-19 and mucormycosis. We aim to conduct a systematic review of literature to find out the patient’s characteristics having mucormycosis and COVID-19.

Methods: We searched the electronic database of PubMed and Google Scholar from inception until May 13, 2021 using keywords. We retrieved all the granular details of case reports/series of patients with mucormycosis, and COVID-19 reported world-wide. Subsequently we analyzed the patient characteristics, associated comorbidities, location of mucormycosis, use of steroids and its outcome in people with COVID-19.

Results: Overall, 101 cases of mucormycosis in people with COVID-19 have been reported, of which 82 cases were from India and 19 from the rest of the world. Mucormycosis was predominantly seen in males (78.9%), both in people who were active (59.4%) or recovered (40.6%) from COVID-19. Pre-existing diabetes mellitus (DM) was present in 80% of cases, while concomitant diabetic ketoacidosis (DKA) was present in 14.9%. Corticosteroid intake for the treatment of COVID-19 was recorded in 76.3% of cases. Mucormycosis involving nose and sinuses (88.9%) was most common followed by rhino-orbital (56.7%). Mortality was noted in 30.7% of the cases.

Conclusion: An unholy trinity of diabetes, rampant use of corticosteroid in a background of COVID-19 appears to increase mucormycosis. All efforts should be made to maintain optimal glucose and only judicious use of corticosteroids in patients with COVID-19.

© 2021 Diabetes India. Published by Elsevier Ltd. All rights reserved.

1. Introduction

Coronavirus disease 2019 (COVID-19) caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) has been associated with a wide range of opportunistic bacterial and fungal infections [1]. Both Aspergillus and Candida have been reported as the main fungal pathogens for co-infection in people with COVID-19 [2]. Recently, several cases of mucormycosis in people with COVID-19 have been increasingly reported world-wide, in particular from India. The primary reason that appears to be facilitating Mucorales spores to germinate in people with COVID-19 is an ideal environment of low oxygen (hypoxia), high glucose (diabetes, new-onset hyperglycemia, steroid-induced hyperglycemia), acidic medium (metabolic acidosis, diabetic ketoacidosis [DKA]), high iron levels (increased ferritins) and decreased phagocytic activity of white blood cells (WBC) due to immunosuppression (SARS-CoV-2 mediated, steroid-mediated or background comorbidities) coupled with several other shared risk factors including prolonged hospitalization with or without mechanical ventilators.

Phycomycosis or zygomycosis was first described in 1885 by Paltauf [3] and later coined as Mucormycosis in 1957 by Baker [4] an American pathologist for an aggressive infection caused by Rhizopus. Mucormycosis is an uncommon but a fatal fungal infection that usually affects patients with altered immunity. Mucormycosis is an angioinvasive disease caused by mold fungi of the

---

* Corresponding author. G.D Hospital & Diabetes Institute, Kolkata, 700013, India.
E-mail address: drawadheshkumarsingh@gmail.com (A.K. Singh).
**2. Methods**

A systematic literature search was conducted in the electronic database of PubMed and Google Scholar from inception until May 13, 2021 using keyword “COVID-19”, “SARS CoV-2”, AND “Mucormycosis”, “Zygomycosis”, “Phycomycosis”, “Mucorales”, “Mucor”, “Rhizopus”, “Rhizomucor”, “Cunninghamella”, and “Absidia”. Details of all the cases that reported mucormycosis (both confirmed and suspected) in people with COVID-19 so far, were retrieved. Characteristics of each patient was collected on excel sheet and analyzed on various endpoints and outcomes. Two authors independently checked the veracity of data.

**3. Results**

Overall, 28 articles were found to report the original case(s) from the database of PubMed (24/28) and Google Scholar (4/28) [17–44]. A total of 101 cases of mucormycosis (including confirmed [95/101] and suspected [6/101]) in people with confirmed (RT-PCR diagnosis) COVID-19 were retrieved (Table 1). Largely, 82 cases (81.2%) of mucormycosis in patients with COVID-19 were reported from India, followed by 9 cases (8.9%) from USA and 3 cases (3.1%) from Iran. Only 19 (18.8%) cases as of now were reported from other parts of the world. One study by Satish et al. [25] that reported 11 case-series of mucormycosis in people with COVID-19 from India lacked granular detail of every patient and therefore excluded from some of the analysis. Pooled data from this study showed mucormycosis was predominantly seen in males (78.9%), both in people who were active (59.4%) or recovered (40.6%) from COVID-19. Pre-existing COVID-19 was seen in 37.7% of cases, while concomitant DKA was present in nearly 15% of people with mucormycosis and COVID-19. Pre-existing DM accounted for 83.3% of mucormycosis in people with COVID-19, followed by cancer (3.0%). Pre-existing DM accounted for 80% of cases, while concomitant DKA was present in nearly 15% of people with mucormycosis and COVID-19. History of corticosteroid intake for the treatment of COVID-19 was present in 76.3% of cases, followed by remdesivir (20.6%) and tocilizumab (4.1%). Commonest organ involved with mucormycosis was nose and sinus (88.9%), followed by rhino-orbital (56.7%) and ROCM type (22.2%). Overall mortality was noted in 30.7% of the cases. Table 2 summarizes the findings from 101 cases of mucormycosis in people with COVID-19.
Table 1
Mucormycosis in COVID-19 — Summary of 101 cases reported world-wide till May 2021.

| First author | Place (of report) | N | Age, range, M/ F | Comorbidities | Confirmed/ Suspected COVID-19 (Active/Recovered) | Treatment received for COVID-19 | Confirmed/Suspected Mucor | Location of mucormycosis | Outcome |
|--------------|-------------------|---|------------------|---------------|---------------------------------------------|--------------------------------|---------------------------|--------------------------|---------|
| **Case report/series from India** | | | | | | | | | |
| Mehta et al. 17 | Mumbai | 1 | 60, M | Y | N | Confirmed, A | Y | Y | N | Confirm | Y | Y | N | N | N | N | Death |
| Garg et al. 18 | Chandigarh | 1 | 55, M | Y | N | Confirmed, A | Y | N | Y | Confirm | Y | Y | N | N | N | Y | Improving |
| Maini et al. 19 | Mumbai | 1 | 38, M | N | N | Confirmed, R | Y | N | Y | Confirm | Y | Y | N | N | N | N | Improved |
| Saldanha et al. 20 | Mangalore | 1 | 32, F | Y | N | Confirmed, A | N | N | N | Confirm | Y | Y | N | N | N | N | Improved |
| Revannavar et al. 21 | Mangalore | 1 | Middle age, F, Y, NDD | N | N | Confirmed, A | N | N | N | Confirm | Y | Y | N | N | N | N | Improved |
| Sen et al. 22 | Mumbai | 6 | 46.2–73.9, M: 6 | Y | N | Confirmed, A: 1 | R: 5 | N: 1 | N | Confirm: 5, Suspect: 1 | Y: All | Y: All | Y: 5 | N: 1 | N | N | Improving |
| Sarkar et al. 23 | Chandigarh | 1 | 55, M | Y | N | Confirmed, A | Y | N | N | Confirm | Y: All | Y: All | Y: 1 | N | N | N | Death: 4, Improved: 2, Unchanged: 4 |
| Mishra et al. 24 | Bangalore | 10 | 37-78, M: 9 | Y | N | Confirmed, A: 10 | Y: 6 | N: 4 | Y: 1 | N: 9 | N: 4 | Y: 6 | N: 4 | Y | Y | N | N | N | Death: 4, Improved: 5 |
| Satish et al. 25 | Bangalore | 11 | 30-74, M: NR | Y: Majority | N | N | Confirmed, A: 11 | Y | Y | N | Confirm | Y: Majority | Y: Majority | Y: 14 | N: 6 | N: 4 | N: 9 | 14 | N: 3 | Death: 7 |
| Mootry et al. 26 | Mangalore | 17 | 30-73, M: 15 | N: 2 | Y | Confirmed, A: 4 | R: 13 | Y: 15 | N: 2 | Confirm | Y: All | Y: All | N | N | N | N | Improving |
| Sharma et al. 27 | Jaipur | 23 | NR | M: 15 | N: 2 | Confirmed, A: 4 | R: 19 | Y: 21 | N: 2 | Confirm | All | Y: All | Y: 10 | Y: 2 | N | N | N | N | Death: 2 |
| | | | | | | | | | | | | | | | | | | | | |
| **Case report/series from other parts of world** | | | | | | | | | |
| Hanley et al. 28 | UK | 1 | 22, M | Y | N | Confirmed, A | N | N | N | Confirm | N | N | N | N | N | N | Death |
| Dallalzadeh et al. 29 | USA | 2 | 36, M | Y:2 | DKA: 2 | N | N | N | Confirmed | N | N | N | N | N | N | N | N | Death |
| Werthman-E et al. 30 | USA | 1 | 33, F | N, DKA | N | N | N | Confirmed | A | N | N | confirm | Y | Y | N | N | N | N | Death |
| Placik et al. 31 | USA | 1 | 49, M | N | N | Confirmed, A | Y | Y | Y | Confirm | N | N | N | N | N | Y | Death |
| Mekkonen et al. 32 | USA | 1 | 60, M | T1DM | N | N | Confirmed, A | Y | N | Y | Confirm | Y | Y | N | N | N | N | Death |
| Alekseyev et al. 33 | USA | 1 | 41, M | T1DM, DKA | N | N | Confirmed, A | Y | N | N | Confirm | Y | N | N | N | N | N | Death |
| Johnson et al. 34 | USA | 1 | 79, M | Y | N | Confirmed, A | Y | N | Y | Confirm | AF + | Confirm | N | N | N | N | Y | N | Improving |
| Kanwar et al. 35 | USA | 1 | 56, M | N | N | Confirmed, A | Y | N | N | Confirm | N | N | N | N | N | N | Death |
| Khatri et al. 36 | USA | 1 | 68, M | Y | N, (HT) | Confirmed, R | Y | N | N | Confirm | N | N | N | N | N | N | Death |
| Monte Junior et al. 37 | Brazil | 1 | 86, M | N | N | Confirmed, A | N | N | N | Confirm | N | N | N | N | N | N | Death |
| Pasero et al. 38 | Italy | 1 | 66, M | N | N | Confirmed, A | N | N | N | Confirm | Y | N | N | N | N | N | Death |
| Bellanger et al. 39 | France | 1 | 55, M | N | Y | Confirmed, A | N | N | N | Confirm | AF + | Confirm | N | N | N | N | Y | N | Death |
| Karimi-G et al. 40 | Iran | 1 | 61, M | N, T1DM | N | N | Confirmed, A | Y | N | Y | Confirm | AF + | Confirm | Y | Y | N | N | N | N | Death |
| Veisi et al. 41 | Iran | 2 | 40, F; 54, M | Y:1 | N | Confirmed, A: 1 | Y: 2 | N: 2 | Y: 2 | Confirm, All | Y: 2 | Y: 2 | Y: 1 | N: 2 | N: 1 | N | 1 | Recovered: 1 |

(continued on next page)
pathological hallmark of mucormycosis. Microbiological identification of the hyphae based on diameter, presence or absence of septa, branching angle (right or acute branching), and pigmentation, differentiates it from other fungal infections. The 1950 Smith and Krichner [47] criteria for the clinical diagnosis of mucormycosis are still considered to be gold standard and include:

(i) Black, necrotic turbinates easily mistaken for dried, crusted blood,
(ii) Blood-tinged nasal discharge and facial pain, both on the same side,
(iii) Soft peri-orbital or peri-nasal swelling with discoloration and induration,
(iv) Proptosis of the eyelid, proptosis of the eyeball and complete ophthalmoplegia and, (v) Multiple cranial nerve palsies unrelated to documented lesions.

A 2019 nationwide multi-center study of 388 confirmed or suspected cases of mucormycosis in India prior to COVID-19, Prakash et al. found that 18% had DKA and 57% of patients had uncontrolled DM [48]. Similarly, in a data of 465 cases of mucormycosis without COVID-19 in India, Patel et al. [49] has shown that rhino-orbital presentation was the most common (67.7%), followed by pulmonary (13.3%) and cutaneous type (10.5%).

The predisposing factors associated with mucormycosis in Indians include DM (73.5%), malignancy (9.0%) and organ transplantation (7.7%) [49]. Presence of DM significantly increases the odds of contracting ROCM by 7.5-fold (Odds ratio 7.55, P = 0.001) as shown in a prospective Indian study, prior to COVID-19 pandemic [50]. In a recent systematic review conducted until April 9, 2021 by John et al. [51] that reported the findings of 41 confirmed mucormycosis cases in people with COVID-19, DM was reported in 93% of cases, while 88% were receiving corticosteroids. These findings are consistent with our findings of even larger case series of 101 mucormycosis cases (95 confirmed and 6 suspected) in Covid-19, where 80% cases had DM, and more than two-third (76.3%) received a course of corticosteroids. Collectively, these findings suggest a familiar connection of mucormycosis, diabetes and steroid, in people with COVID-19.

Since there are no studies that compared patients of mucormycosis in non-diabetic COVID-19 who did not receive steroids versus COVID-19 patients who received steroids and developed mucormycosis, it is difficult to establish a causal effect relationship between COVID-19 and mucormycosis in relation to corticosteroids. Nonetheless, there appears to be a number of triggers that may precipitate mucormycosis in people with COVID-19 in relation to corticosteroids:

(i) Presence of DM with or without DKA increases the risk of contracting mucormycosis and DM is often associated with an increased severity of COVID-19,
(ii) Uncontrolled hyperglycemia and precipitation of DKA is often observed due to corticosteroid intake. Low pH due to acidosis is a fertile media for mucor spores to germinate. Moreover, steroid use reduces the phagocytic activity of WBC (both first line and second line defense mechanism), causes impairment of bronchoalveolar macrophages migration, ingestion, and phagolysosome fusion, making a diabetic patient exceptionally vulnerable to mucormycosis.
(iii) COVID-19 often causes endothelialitis, endothelial damage, thrombosis, lymphopenia, and reduction in CD4+ and CD8+ T-cell level and thus predisposes to secondary or opportunistic fungal infection,
(iv) Free available iron is an ideal resource for mucormycosis. Hyperglycemia causes glycosylation of transferrin and

| First author | Place of report | N | Age, range, M/F | Comorbidities | Confirmed/Suspected COVID-19 (Active/Recovered) | Treatment received for COVID-19 | Confirmed/Suspected Mucor Location of mucormycosis | Outcome |
|--------------|-----------------|---|-----------------|---------------|-----------------------------------------------|-----------------------------|-----------------------------------------------|---------|
| Sargin et al. | Turkey | 1 | 56, F | | Y | Y, DKA | N | N | Con firm, R | N | N | N | N | Con firm Y | Y | Y | Y | N | N | N | Death |
| Waizel-H et al. | Mexico | 1 | 24, F | | Y | | N | DKA | N | N | Con firm, A | N | N | N | N | Con firm Y | Y | N | N | N | N | N | Death |
| Zurl et al. | Austria | 1 | 53, M | | Y | | V | Leukemia | N | N | Con firm, A | Y | N | N | N | Con firm, Autopsy Y | N | N | N | Y | N | N | Death |

DM: Diabetes mellitus, CNS: Central nervous system, GIT: Gastro-intestinal tract, M: Male, F: Female, T1DM: Type 1 diabetes mellitus, DKA: Diabetic ketoacidosis, NOD: New-onset diabetes, NDD: Newly detected diabetes, A: Active COVID-19, R: Recovered COVID-19, LFU: Lost to follow-up, LAMA: Left against medical advice.
ferritin, and reduces iron binding allowing increased free iron. Moreover, increase in cytokines in patients with COVID-19 especially interleukin-6, increases free iron by increasing ferritin levels due to increased synthesis and decreased iron transport. Furthermore, concomitant acidosis increases free iron by the same mechanism and additionally by reducing the ability of transferrin to chelate iron.

(v) High glucose, low pH, free iron, and ketones in presence of decreased phagocytic activity of WBC, enhances the growth of mucor. In addition, it enhances the expression of glucose-regulator protein 78 (GRP-78) of endothelium cells and fungal ligand spore coating homolog (CoTh) protein, enabling angio-invasion, hematogenous dissemination and tissue necrosis [52].

Fig. 1 depicts the postulated mechanism of increased propensity of having mucormycosis infection in COVID-19 patients.

There are certain limitations to conduct this kind of systematic review based on case reports/series subject to publication biases and considerable heterogeneity in reporting cases. It is highly likely that reported cases of mucormycosis may be an underrepresentation of the real burden owing to difficulty in making a microbiological or histopathological diagnosis especially in a raging pandemic setting. While some case reports had every minute detail, other did not report important parameter, for example duration of DM, lack of baseline HbA1c data and duration of diabetes for majority of DM patients. Secondly, the lack of a denominator value may not allow the true estimation of mucormycosis incidence in people with COVID-19 compounded by the lack of control. Thirdly, defining active and recovered COVID-19 and its relation to the onset of mucormycosis could be difficult considering the lower sensitivity of confirmatory RT-PCR. Finally, evaluating the outcomes in people with mucormycosis and COVID-19 could be difficult at the moment because these case reports have been published while many of these patients are still under treatment. Other minor limitations have been highlighted in Table 2.

5. Conclusions

Increase in mucormycosis in Indian context appears to be an unholy intersection of trinity of diabetes (high prevalence genetically), rampant use of corticosteroid (increases blood glucose and
opportunistic fungal infection) and COVID-19 (cytokine storm, lymphopenia, endothelial damage). All efforts should be made to maintain optimal hyperglycemia and only judicious evidence-based use of corticosteroids in patients with COVID-19 is recommended in order to reduce the burden of fatal mucormycosis.

Funding
No funding.

Author’s contribution
AKS conceptualized, searched the literature and wrote first draft; RS made the tables, analyzed the data and revised the first draft, SRJ and AM edited the final draft. All authors agreed mutually to submit for publication.

Authorship
All authors meet the International Committee of Medical Journal Editors (ICMJE) criteria for authorship and take responsibility for the integrity of the work. They confirm that this paper will not be published elsewhere in the same form, in English or in any other language, including electronically.

Declaration of competing interest
We hereby declare that we have no conflict of interest, related to this article titled “Mucormycosis in COVID-19: A Systematic Review of Cases Reported Worldwide and in India”.

References
[1] Kubin CJ, McConville TH, Dietz D, et al. Characterization of bacterial and fungal infections in hospitalized patients with COVID-19 and factors associated with healthcare-associated infections. Open Forum Infectious Diseases; 2021. https://doi.org/10.1093/ofid/ofab201. ofab201.
[2] Song G, Liang G, Liu W. Fungal Co-infections associated with global COVID-19 pandemic: a clinical and diagnostic perspective from China. Mycopathologia 2020 Aug;185(4):599–606.
[3] Paltauf A. Mycosis mucorina. Virchows Arch Pathol Anat Physiol Klin Med 1885;102:543–64.
[4] Baker RD. Mucormycosis—a new disease? J Am Med Assoc 1957;163:805–8.
[5] Eucker J, Sezer O, Graf B, Possinger K. Mucormycoses. Mycoses. 2001;44(7):253–60.
[6] Sugar AM. In: Mandell GL, Bennett JE, Dolin R, editors. Mandell, Douglas, and Bennett’s principles and practice of infectious diseases. fifth ed. New York, USA: Churchill Livingstone; 2000.
[7] Skiada A, Pavleas I, Drogari-Apiranthitou M. Epidemiology and diagnosis of mucormycosis: an Update. J Fungi 2020;6(4):265.
[8] Chander J, Kaur M, Singla N, et al. Mucormycosis: battle with the deadly enemy over a five-year period in India. J. Fungi 2018;4(2):46. https://doi.org/10.3390/jof4020046.
[9] Prakash H, Chakrabarti A. Global epidemiology of mucormycosis. J Fungi 2019;5:26.
[10] International Diabetes Federation. Idf diabetes atlas. Available online: https://diabetesatlas.org/en/resources/. [Accessed 10 May 2021].
[11] Jeong W, Keighley C, Wolfe R, et al. The epidemiology and clinical manifestations of mucormycosis: a systematic review and meta-analysis of case reports. Clin Microbiol Infect 2019;25:26–34.
[12] Lionakis MS, Kontoyiannis DP. Glucocorticoids and invasive fungal infections. Lancet 2003;362:1828–38.
[13] Hoang K, Abdo T, Reinersman JM, Lu R, Higuita NIA. A case of invasive pulmonary mucormycosis resulting from short courses of corticosteroids in a well-controlled diabetic patient. Med Mycol Case Rep 2020;29(1):22–4.
[14] Skiada A, Pagano I, Groll A, et al. Zygomycosis in Europe: analysis of 230 cases accrued by the registry of the European confederation of medical Mycology (ECMM) working group on zygomycosis between 2005 and 2007. Clin Microbiol Infect 2011;17(12):1859–67.
Moorthy A, Gaikwad R, Krishna S, et al. SARS-CoV-2, uncontrolled diabetes and mucormycosis in a COVID-19 patient: a case report. J Surg Case Rep 2021 May 4;82:105957.

Saldanha M, Reddy R, Vincent MJ. Title of the article: paranasal mucormycosis in a COVID-19 patient. Indian J Otolaryngol Head Neck Surg 2021 Apr;73(2):211–4. https://doi.org/10.1007/s00161-021-06274-0 [Online ahead of print].

Revannavar SM, PS, Samaga L. COVID-19 triggering mucormycosis in a susceptible patient: a new phenomenon in the developing world? BMJ Case Rep 2021 Apr 27;14(4). e241663.

Sen M, Lahane S, Lahane TP, et al. Mucor in a viral land: a tale of two pathogens. Indian J Ophthalmol 2021;69:244–52.

Sarkar S, Kokhale T, Choudhury SS, Deb AK. COVID-19 and orbital mucormycosis. Indian J Ophthalmol 2021 Apr;69(4):1002–4.

Mishra N, Mutya VSS, Thomas A, et al. A case series of invasive mucormycosis in patients with COVID-19 infection. Int J Otorhinolaryngol Head Neck Surg 2021 May;7(5):867–70.

Satriah D, Joy D, Ross A, Balasubramanayam. Mucormycosis coinfection associated with global COVID-19: a case series from India. Int J Otorhinolaryngol Head Neck Surg 2021 May;7(5):815–20.

Moorthy A, Gaikwad R, Krishna S, et al. SARS-CoV-2, uncontrolled diabetes and corticosteroids-an unholy trinity in invasive fungal infections of the maxillofacial region? A retrospective, multi-center analysis. J Maxillofac Oral Surg 2021 Mar 6:1–8. https://doi.org/10.1007/s12663-021-01532-1 [Online ahead of print].

Sharma S, Grover M, Bhardwaj S, Sandani S, Kataria T. Post coronavirus disease mucormycosis: a deadly addition to the pandemic spectrum. J Laryngol Otol 2021 Apr 8:1–6. https://doi.org/10.1017/S0022215121000992 [Online ahead of print].

Hanley B, Naresh KN, Roufouse C, et al. Histopathological findings and viral tropism in UK patients with severe fatal COVID-19: a post-mortem study. Lancet Microbe 2020 Oct;1(6):e245–53.

Dallalzadeh LO, Ozzello DJ, Liu CY, Kikkawa DO, Korn BS. Secondary infection with rhino-orbital cerebral mucormycosis associated with COVID-19. Orbit 2021 Mar 23:1–4. https://doi.org/10.1080/11206721.2021.1903044 [Online ahead of print].

Werthman-Ehrenreich A. Mucormycosis with orbital compartment syndrome in a patient with COVID-19. Am J Emerg Med 2021;42:264.e8. In press.

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 Nov;15(11):2378–81.

Meekonzen ZK, Ashraf DC, Jankowski T, et al. Acute invasive rhino-orbital mucormycosis in a patient with COVID-19-associated acute respiratory distress syndrome. Ophthalmic Plast Reconstr Surg 2021;37:40–80.

Alekseyev K, Didenko L, Chaudhry B. Rhinocerebral mucormycosis and COVID-19 pneumonia. J Med Cases 2021;12(3):85–89.

Johnson AK, Ghazarian Z, Cendrowski KD, Persichino JC. Pulmonary aspergillosis and mucormycosis in a patient with COVID-19. Med Mycol Case Rep 2021 Jun;32:64–7.

Kanwar A, Jordan A, Olewiler S, Wehberg K, Cortes M, Jackson BR. A fatal case of Rhizopus azygosporus pneumonia following COVID-19. J Fungi (Basel) 2021 Feb 28;7(3):174.

Khati A, Chang KM, Berlinrut I, Wallach. Mucormycosis after Coronavirus disease 2019 infection in a heart transplant recipient - case report and review of literature. J Mycol Med 2021 Apr 2;31(2):101125.

Monte Jr ESD, Santos MELD, Ribeiro IB, et al. Rare and fatal gastrointestinal mucormycosis (zygomycosis) in a COVID-19 patient: a case report. Clin Endosc 2020 Nov;53(6):746–9.

Pasero D, Sanna S, Liperi C, et al. A challenging complication following SARS-CoV-2 infection: a case of pulmonary mucormycosis. Infection 2020;1–6.

Bellanger AP, Navellou JC, Lepiller Q, et al. Mixed mold infection with Aspergillus fumigatus and Rhizopus microsporus in a severe acute respiratory syndrome Coronavirus 2 (SARS-CoV-2) patient. S2666-9919(21)00030-0 Infect Dis News 2021 Jan 27. https://doi.org/10.1016/j.idnow.2021.01.010 [Online ahead of print].

Karimi-Galouagh M, Arastou S, Haseli S. Fulminant mucormycosis complicating coronavirus disease 2019 (COVID-19). Int Forum Allergy Rhinol 2021 Mar 1. https://doi.org/10.1002/alr.22785 [Online ahead of print].

Veisi A, Bagheri A, Esbaghi M, Rikhtegar MH, Rezaei Kanavi M, Farjadian R. Rhinocerebral mucormycosis during steroid therapy in COVID-19 patients: a case report. 11206721211009450 Eur J Otolaryngol 2021 Apr 10. https://doi.org/10.1177/11206721211009450 [Online ahead of print].

Sargin F, Akbulut M, Karaduman S, Srgurtekin H. Severe rhinocerebral mucormycosis case developed after COVID-19. J Bacteriol Parasitol 2021;12:386.

Waizel-Haia S, Guerero-Paz JA, Sanchez-Hurtado L, et al. A case of fatal rhinocerebral mucormycosis associated with new onset diabetic ketoacidosis and COVID-19. Cureus 2021;13:e13163.

Zuri C, Hoenigl M, Schulz E, et al. Autopsy proven pulmonary mucormycosis due to Rhizopus microsporus in a critically ill COVID-19 patient with underlying hematological malignancy. J Fungi (Basel). 2021 Jan 27;7(2):88.

Sugars AM, Mucormycosis. Clin Infect Dis 1992;14:5126–9.

Peterson KL, Wang M, Canalis FR, Abemayor E. Rhinocerebral mucormycosis: evolution of the disease and treatment options. Laryngoscope 1997;107:855–62.

Smith HW, Kirchner JA. Cerebral mucor-mycosis: a report of 3 cases. Arch Otolaryngol 1950;68:715–26.

Prakash H, Ghosh AK, Rudramurthy SM, et al. A prospective multicenter study on mucormycosis in India: epidemiology, diagnosis, and treatment. Med Mycol 2019;57:395–402.

Patek A, Kaur H, Xess I, et al. A multicentre observational study on the epidemiology, risk factors, management and outcomes of mucormycosis in India. Clin Microbiol Infect 2020;26(7):944.e9-944.e15.

Bala K, Chander J, Handa U, et al. A prospective study of mucormycosis in north India: experience from a tertiary care hospital. Med Mycol 2015;53(3):248–57.

John TM, Jacob CN, Kontoyiannis DP. When uncontrolled diabetes mellitus and severe COVID-19 converge: the perfect storm for mucormycosis. J Fungi (Basel) 2021 Apr 15;7(4):298.

Baldin C, Ibrahim AS. Molecular mechanisms of mucormycosis -The bitter and the sweet. PLoS Pathog 2017;13(8). e1006408.