Magnetic resonance imaging spectrum of COVID-associated rhino-orbital-cerebral mucormycosis and assessment of anatomical severity

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Abstract

Objectives: To describe the extent and imaging findings of COVID-associated rhino-orbital-cerebral mucormycosis on magnetic resonance imaging and to evaluate the value of MRI severity score in grading the extent of involvement.

Methods: Proven cases of ROCM with a history of concurrent or recently (<6 weeks) treated COVID-19 underwent MRI at the initial presentation. Findings were charted for each anatomical structure and the extent of involvement was scored for sinonasal, extra-sinus soft tissues, orbits, and brain. MR severity score was defined by summing up the individual scores of each compartment (sinonasal 20, orbital 20, soft tissue 10, and brain 10) and a total score out of 60 was assigned.

Results: A total of 47 patients were included in our study with variable involvement of sinonasal compartment (n = 43), extra-sinus soft tissue (n = 25), orbits (n = 23), and brain (n = 17). In the sinonasal compartment, T2, DWI, and post-contrast T1 were the most useful sequences. A significantly higher mean sinonasal score was associated with mortality (p = 0.007). In the orbits, a combination of STIR (orbital fat and extraconal muscles), DWI (optic nerves), and post-contrast images (superior ophthalmic vein) were the most accurate sequences. A higher mean orbital score was associated with vision loss (p = 0.001). Patients with uncontrolled diabetes had greater extent of cranial involvement.

Conclusion: A combination of magnetic resonance sequences is required to correctly evaluate the involvement of individual structures and thus to assign the correct MR scoring. The proposed MR severity score can effectively and objectively evaluate the severity of COVID-associated ROCM.

Keywords
Magnetic resonance imaging, mucormycosis, COVID-19

Introduction
Rhino-orbital-cerebral mucormycosis (ROCM) is a life-threatening condition resulting from infection of sinonasal cavities, orbits, and brain by a group of fungal organisms belonging to the order of Mucorales. Before the COVID-19 pandemic, mucormycosis was considered a rare disease with an annual estimated incidence of 1.7 cases/million and reported mortality of up to 54%.1 The first documentation of COVID-associated mucormycosis (CAM) was reported in August 2020 in the USA in a 33-year-old female who presented with orbital compartment syndrome.2 Since then, various reports and studies have been published from the USA, Iran, Brazil, Italy, Turkey, United Kingdom, and India.3-6 CAM obtained epidemic proportions in India with seven states declaring it as an epidemic.

Endoscopic sampling and histopathological evaluation along with culture remain the gold standard technique for its diagnosis. CT scan and MRI are the commonly utilized imaging modalities to evaluate the extent of the spread. MRI is the most sensitive technique for the diagnosis and staging of the disease. This study aimed to review the spectrum of MR imaging appearances and the spread pattern of the proven cases of COVID-associated ROCM. Based on the extent of involvement, we evaluated the performance of a semiquantitative MR severity score designed to assess the severity of ROCM.

Materials and methods

Subjects
This was a prospective observational study done in May 2021 performed at tertiary care University-based Hospital. The study was approved by Institutional Ethical Committee and informed consent was obtained from all the patients/guardians.
included in this study. The inclusion criteria were (i) proven cases of ROCM by direct microscopy of the deep or endoscopy-guided nasal swab, paranasal sinus, or orbital tissue using a KOH mount, (ii) patients referred to the Radiology department for initial MRI, and (iii) history of concurrent or recently (<6 weeks) treated COVID-19. MRI performed after surgical treatment was not included.

**Magnetic resonance imaging scan**

Magnetic resonance imaging was performed on a 1.5 T superconducting magnet (Magnetom Avanto, Siemens Medical System, Erlangen-Germany). MR of the Brain, orbits, PNS (paranasal sinus), and the nasal cavity was done in all the patients in the supine position using an 8-channel bird-cage quadrature head coil. In orbits and sinonasal imaging, T1, T2, Diffusion-weighted imaging, Susceptibility weighted imaging (SWI), and STIR images were acquired in multiple planes followed by contrast-enhanced three plane T1 W fat-saturated images. Brain assessment protocol included T1 (non-fat-suppressed), T2, FLAIR, DWI, SWI, and post-contrast scans. For assessment of cranial vessels, MR angiography time of flight technique was employed.

**Magnetic resonance scan evaluation**

Two radiologist (IK and AV) with 1 and 17 years of experience, evaluated the images in consensus. A systematic evaluation and an anatomical scoring of the involved structures were done as given in Table 1.

**Statistical analysis**

The statistical analysis was performed with the aid of SPSS version 16.0 (SPSS, Inc., Chicago, IL, USA). Descriptive statistics were applied for the evaluation of imaging appearances on each sequence. An independent-sample t-test was used to compare mean scores between two groups.

**Results**

A total of 47 patients were included in our study with a median age of 51 (19–75) years and a male:female ratio of 1:1.

| Table 1. Proposed MR severity score for extent of involvement. |
|---------------------------------------------------------------|
| **Score right** | **Score left** | **Total score** |
| **Sinonasal score** | | 20 |
| Maxillary sinus | 1 | 1 |
| <50% | 2 |
| >50% | |
| Ethmoid sinus | 1 | 1 |
| <50% | 2 |
| >50% | |
| Sphenoid sinus | 1 | 1 |
| Fronto nasal sinuses | 1 | 1 |
| Inferior nasal turbinate | 1 | 1 |
| Middle nasal turbinate | 1 | 1 |
| **Orbital score** | | 20 |
| Preseptal | 1 | 1 |
| Extraconal | 1 | 1 |
| Intraconal | 1 | 1 |
| Extraocular muscles | 1 | 1 |
| Optic nerve | 2 | 2 |
| Superior ophthalmic vein | 1 | 1 |
| Globe | 2 | 2 |
| Apex | 1 | 1 |
| **Soft tissue score** | | 10 |
| Pre-maxillary region | 1 | 1 |
| Retroantral fat | 1 | 1 |
| Pterygopalatine fossa | 1 | 1 |
| Infratemporal fossa | 1 | 1 |
| Palate | 1 | 1 |
| **Cerebral score** | | 10 |
| Meningeal thickening | 1 | 1 |
| Lacunar infarcts | 1 | 1 |
| Perineural spread | 1 | 1 |
| Cavernous sinus and internal carotid artery | 1 | 1 |
| Territorial infarct | 2 | 2 |
| Encephalitis | 2 | 2 |
| Abscess | 2 | 2 |
| **Total MR severity score** | 20+20+10+10 | 60 |
26:21. Three of these patients were currently admitted with COVID at the time of scan whereas 44 of these patients had a history of COVID-19 illness in the last 1–2 months. Of these, 29 patients were managed in the hospital because of severe COVID, and the rest were managed with home quarantine. Of the 29 admitted, 24 had required oxygen therapy. 34 patients had a history of steroid intake during their illness with COVID. 40 patients received no vaccine for COVID while seven had received non-replicating viral vector vaccine ChAdOx1 (Covishield®, AstraZeneca), of which only one had received two doses. 19 patients had undergone HRCT of the thorax for evaluation of COVID pneumonia with a mean HRCT severity score of 14.1 ± 3.36 out of 25 (range 8–22). The severity score used to quantify COVID involvement was calculated based on the extent of the lobar involvement where each of the five lobes were visually scored on a scale of 0–5.46. Patients with preexisting diabetes with mean HbA1c 10.09 ± 2.6.14 patients had controlled diabetes (HbA1c 7.54 ± 2.2), whereas 33 had uncontrolled diabetes (HbA1c 11.13 ± 2.0) on insulin or oral medications. Other comorbidities present in our cohort were hypertension (n = 11), and chronic kidney disease (n = 2). Most common clinical presentation in our patients were facial pain and swelling (n = 40), sinus pain (n = 45), fever (n = 7), nasal discharge (n = 23), ophthalmoplegia (n = 9), vision loss (n = 13), and proptosis (n = 2).

### Extent of involvement

A total of 43 patients showed sinonasal involvement in our study. Maxillary sinus involvement was most common (71%) followed by ethmoid sinus and sphenoid sinuses. In the nasal cavity, right-sided middle and inferior turbinates were more frequently involved compared to the left-sided nasal cavity (Table 2). 25 cases showed involvement of surrounding soft tissues in the form of pre-maxillary region (n = 18 on right side and n = 8 on left side), retroantral fat (n = 15 on right side and n = 8 on left side), pterygopalatine fossa (n = 5 on right side and n = 4 on left side), infratemporal fossa (n = 15 on right side and n = 8 on left side), and palate (n = 2). Orbits were involved in 23 cases. The involvement of extraconal and preseptal compartments was the most common site in the orbit, followed by extraocular muscles and the intracranial compartment (Table 2).

### Table 2. Summary of the extent of involvement in patients of ROCM.

| Soft tissue involvement | Right | % of cases | Left | % of cases |
|-------------------------|-------|------------|------|------------|
| Pre-maxillary region    | 18    | 38%        | 8    | 17%        |
| Retroantral fat         | 15    | 31%        | 8    | 17%        |
| Pterygopalatine fossa   | 5     | 10%        | 4    | 8%         |
| Infratemporal fossa     | 15    | 31%        | 8    | 17%        |
| Palate                  | 2     | 4%         | 2    | 4%         |
| Orbital involvement     |       |            |      |            |
| Preseptal               | 14    | 29%        | 11   | 23%        |
| Extraconal              | 15    | 31%        | 10   | 21%        |
| Intracranial            | 12    | 25%        | 10   | 21%        |
| Extraocular muscles     | 12    | 25%        | 11   | 23%        |
| Optic nerve             | 7     | 15%        | 6    | 13%        |
| Superior ophthalmic vein| 4     | 8%         | 6    | 13%        |
| Globe                   | 3     | 6%         | 3    | 6%         |
| Apex                    | 7     | 15%        | 3    | 6%         |
| Sinonasal involvement   |       |            |      |            |
| Maxillary sinus         | 33    | 68%        | 34   | 71%        |
| <50%                    | 17    | 35%        | 18   | 38%        |
| >50%                    | 16    | 33%        | 16   | 33%        |
| Ethmoid sinus           | 29    | 61%        | 28   | 59%        |
| <50%                    | 8     | 17%        | 10   | 21%        |
| >50%                    | 21    | 44%        | 18   | 37%        |
| Sphenoid sinus          | 28    | 58%        | 23   | 48%        |
| Frontal sinus           | 18    | 38%        | 14   | 29%        |
| Inferior nasal turbinate| 13    | 27%        | 6    | 13%        |
| Middle nasal turbinate   | 18    | 38%        | 5    | 10%        |
| Cerebral involvement    |       |            |      |            |
| Meningeal thickening    | 12    | 25%        |      |            |
| Cavernous sinus and internal carotid artery | 10 | 21% |
| Lacunar infarct         | 4     | 8%         |      |            |
| Territorial infarct     | 3     | 6%         |      |            |
| Abscesses               | 9     | 19%        |      |            |
| Perineural involvement  | 5     | 10%        |      |            |
patients in our study had involvement of the brain. Imaging findings in these patients were abnormal meningeal thickening and enhancement (n = 12), cavernous sinus involvement and ICA narrowing (n = 10), lacunar infarcts (n = 4), territorial infarct (n = 3), abscesses (n = 9), cranial nerve involvement (n = 5), and T2/FLAIR hyperintense lesion at the exit areas of cranial nerves (Table 2).

**Magnetic resonance imaging severity score and outcome**

Based on our proposed anatomical scoring system, we obtained MR severity scores of 1–34 out of 60 (Table 3). Two patients with proven mucormycosis had scores of 1 each with preseptal edema and unilateral inferior turbinate involvement being the only findings on imaging respectively. Mean scores of sinonasal compartments ranged between 0 and 12 and were higher in right-sided sinuses and nasal cavities. Mean sinonasal score (out of 10) on right and left sides were 3.55 ± 2.24 and 3.32 ± 2.18, respectively, and a higher sinonasal score was associated with death (5.2 ± 0.8), in the left sinonasal compartment compared to those who survived (2.7 ± 1.9); p-value 0.007 (Table 4). Conservative medical treatment was given in nine patients, whereas 38 patients underwent sinonasal debridement. The mean total sinonasal score (9.34 ± 4.4) was significantly higher (p = 0.04) in patients undergoing surgical management compared to those who were conservatively managed (6.0 ± 4.0). Right-sided surrounding soft tissues were much more extensively involved compared to the left side. A significantly higher unilateral soft tissue score (2.1 ± 1.9) out of five was associated with mortality compared to those who survived (0.58 ± 1.2).

Right-sided orbits showed higher mean scores (2.11 ± 2.66) compared to the left side (1.8 ± 2.55). Patients with vision loss had a significantly higher (p < 0.001) total orbital score (8.1 ± 3.8) out of 20, compared to those who had intact vision (2.2 ± 2.5). Orbital exenteration was done in 15 cases and those requiring it had a significantly higher total orbital score (7.6 ± 2.7) compared to those who did not require it (2.2 ± 3.1).

We observed that patients with uncontrolled diabetes had significantly higher mean CNS scores and total MRI severity scores compared to those with controlled diabetes. Comparisons were also made between the mean total scores and that of each compartment based on hospital admission, oxygen therapy, and steroid intake during COVID treatment and COVID vaccination status, however, the differences were not significant statistically.

**Imaging pattern on magnetic resonance sequences**

Table 5 summarizes the imaging appearances on individual MRI sequences in sinonasal, extra-sinus soft tissue, and orbital compartments. In the sinonasal involvement, the most common appearance was T1 hypo/isointense, T2 hyperintense contents which showed areas of diffusion restriction in 49% of cases (Figure 1). Eight patients showed punctate foci

| Table 3. Mean MRI scores in patients of ROCM (n = 47). |
|-----------------------------------------------------|
|            | Maximum score | Mean score ±SD | Range |
| Sinonasal   |               |                |       |
| Right       | 10            | 3.55 ± 2.24    | 0–6   |
| Left        | 10            | 3.32 ± 2.18    | 0–6   |
| Total       | 20            | 8.7 ± 4.5      | 1–20  |
| Orbit       |               |                |       |
| Right       | 10            | 2.11 ± 2.66    | 0–10  |
| Left        | 10            | 1.8 ± 2.55     | 0–8   |
| Total       | 20            | 3.9 ± 3.94     | 0–15  |
| Surrounding soft tissue | |                |       |
| Right       | 5             | 1.49 ± 1.5     | 0–5   |
| Left        | 5             | 0.96 ± 1.5     | 0–5   |
| Total       | 10            | 1.77 ± 2.07    | 0–8   |
| Cerebral    | 10            | 1.53 ± 1.95    | 0–6   |
| Total score | 60            | 16.6 ± 10.4    | 2–38  |

| Table 4. Comparison of MRI scores with clinical outcome. |
|--------------------------------------------------------|
| MRI score | Outcome present/absent | Mean score | p Value |
| Death (dead (n = 11); Alive (n = 36))                  |
| Right sinonasal | Dead | 4.0 ± 1.6 | 0.021 |
| Left sinonasal  | Dead  | 5.2 ± 0.8 | 0.007 |
| Right soft tissue | Dead  | 1.56 ± 1.59 | 0.60 |
| Left soft tissue | Dead  | 2.1 ± 1.9 | 0.001 |
| Total score    | Dead  | 21.7 ± 8.8 | 0.29 |
| Sinonasal management (Conservative (n = 9); surgical debridement (n = 38)) |
| Right sinonasal | Conservative | 2.33 ± 1.8 | 0.04 |
| Left sinonasal  | Surgical   | 3.8 ± 1.9 | 0.29 |
| Total sinonasal | Conservative | 6.0 ± 4.0 | 0.04 |
| Total score    | Surgical   | 11.0 ± 10.1 | 0.07 |
| Vision loss (absent (n = 34); present (n = 13))       |
| Right orbital  | Absent  | 1.3 ± 2.0 | 0.001 |
| Left orbital   | Absent  | 0.9 ± 2.0 | <0.001 |
| Total orbital  | Absent  | 2.2 ± 2.5 | 0.001 |
| Total score    | Absent  | 8.1 ± 3.8 | <0.001 |
| Orbital exenteration (not done (n = 32); done (n = 15)) |
| Right orbital  | Not done | 1.1 ± 1.6 | <0.001 |
| Left orbital   | Done    | 4.4 ± 2.9 | 0.02 |
| Total orbital  | Not done | 3.1 ± 3.1 | <0.001 |
| Total score    | Not done | 7.6 ± 2.7 | <0.001 |
| Uncontrolled diabetes controlled (n = 14) uncontrolled (n = 33) |
| CNS score   | Controlled | 0.14 ± 0.53 | 0.001 |
| Uncontrolled | Controlled | 2.12 ± 2.1 | 0.05 |
| Total score | Controlled | 12.21 ± 10.1 | 18.45 ± 10.2 |
of blooming on SWI. On post-contrast images, loss of contrast enhancement (LOCE) or “black turbinate sign” was seen in 51% of cases. Based on the percentage of non-enhancing contents (necrosis/ischemic components), sinonasal involvement was graded and >50% necrosis was seen in 5 cases, 25–50% necrosis was noted in 14/43 cases, and 12 cases showed <25% necrosis. T2/STIR hyperintensity was seen in all cases with soft tissue involvement. In post-contrast images, the most common pattern was complete heterogeneous enhancement and LOCE. One-fourth of cases did not show abnormal enhancement in the infratemporal fossa.

For assessment of orbital (extraconal, intraconal, and preseptal) fat involvement, STIR sequence, as well as T1, were the most sensitive sequences while diffusion restriction was seen in 30% of cases (Figure 2). STIR was the most sensitive sequence for extraocular muscles (70%). Diffusion restriction was seen in 10/12 cases (83%), STIR hyperintensity was seen in 4/12 cases (33%). DWI was the most sensitive sequence to identify optic nerve involvement (83%) and post-contrast T1 followed by STIR was most sensitive for the involvement of superior ophthalmic vein (SOV). Meningeal thickening was more common in the basi-temporal region (n = 8) and the right side was more commonly involved (n = 6). Lacunar infarcts were seen in centrum semiovale (n = 2), gangliocapsular region (n = 1), or peritrigonal region (n = 1). Middle cerebral artery (MCA) territory infarcts were seen in 2 cases and 1 case showed coexisting infarcts in the centrum semiovale and hypothalamus (Figure 3). Cranial nerve involvement apart from the optic nerve and cavernous sinus was seen in 3 cases with involvement of the olfactory bulb (n = 2) by fungal abscesses and trigeminal nerves (n = 2) which showed thickening and enhancement and blooming artifacts at their exit zones on SWI. Involvement of cavernous sinus and cavernous segment of ICA was assessed on combination of MRA and post-contrast 3D T1 images and was seen in 10 cases, presenting as non-enhancing bulky cavernous sinus, narrowing/

Table 5. Summary of imaging appearances on individual MRI sequences in sinonasal, extra-sinus soft tissue, and orbital compartments. (Numbers indicated are number of patients).

| Compartment          | T1          | T2/STIR     | DWI (Restriction) | Post contrast |
|----------------------|-------------|-------------|-------------------|--------------|
| Sinonasal (n = 43)   | Hypointense 20 | Hypointense: 6 | CE: 17            |
|                      | Isointense: 13 |              | LOCE: 11          |
|                      | Hyperintense: 10| Hyperintense:21 | Normal enhancement: 6 |
| Soft tissue (n = 25) | Hypo/isointense 20 | Hyperintense:25 | CE: 11            |
|                      |              |              | LOCE: 7           |
| Orbital fat (n = 23) | Hyperintense 5 | Hypointense: 4 | Peripherally enhancing abscess: 7 |
| Extraocular muscles  | Stranding: 18 | Hyperintense:19 |                 |
| (n = 20)             | Increased bulk: 9 | Hyperintense:14 | Enhancement: 6    |
| Optic nerve (n = 12) | Increased bulk/altered signal:2 | Hyperintense: 4 | Hyperenhancement: 2 |
| Superior ophthalmic ve

Figure 1. Axial post contrast (a) image of a patient showing mucosal thickening with loss of contrast enhancement (short white arrow) in left maxillary sinus and large enhancing tissue (black arrow) in right infratemporal fossa along with necrotic areas showing loss of contrast enhancement (white arrow). DWI b1000 (b) image of another patient showing diffusion restriction in tissue involving left maxillary sinus (white dashed arrow). Susceptibility weighted phase images (c) of another patient showing blooming foci in the right maxillary sinus (yellow arrow). Uninvolved left maxillary sinus does not show blooming artifact (yellow dashed arrow).
occlusion of ICA, absence of flow void in ICA, T2 hyperintense wall of ICA, or directly visualized extension of disease from orbit (Figure 4). One case presented with gyriform restriction in bilateral basitemporal lobes, bilateral parietal, and frontal lobes along with adjacent meningeal involvement and was consistent with meningoencephalitis (Figure 3). Nine cases of fungal abscess were seen in our study (temporal lobe \( n = 6 \)), inferior frontal lobe \( (n = 3) \), coexisting cerebellar abscess \( (n = 1) \), which were seen as ring-enhancing lesions \( (n = 8) \), or heterogeneous enhancement \( (n = 1) \). Frontal lobe abscesses were seen involving the olfactory bulb, olfactory sulcus, and gyrus rectus \( (n = 2) \) with one lesion extending up to the head of caudate. 2 cases of temporal lobe abscesses showed contiguous involvement of ipsilateral cavernous sinuses. All these abscesses showed diffusion restriction of the abscess wall and blooming artifacts on SWI (Figure 5) while the abscess center showed facilitated diffusion \( (n = 8) \) or restriction \( (n = 1) \).

**Discussion**

Our results showed that the proposed semiquantitative MR severity score can provide an objective estimate of the extent of disease which correlates well with the clinical outcome. Our data also elaborates the common and uncommon appearance of ROCM on the individual MR sequences and highlights the importance of various sequences for various anatomical structures involved by ROCM.

The presence of preexisting or undiagnosed Diabetes (91–93% cases) and over-zealous steroid usage (88–100%) during COVID treatment have been considered as the main predisposing factors in the development of COVID-associated mucormycosis (CAM) in India. In our study, however, only 66% had a history of steroid intake while preexisting diabetes all but one case. COVID-induced hypoxia, polymorphonuclear dysfunction due to increased expression of the endothelial receptor GRP78 induced by hyperglycemia (diabetes, and/or steroid-induced hyperglycemia), acidic
medium (diabetic ketoacidosis), and high iron levels due to ketoacidosis provides an ideal environment for the development of mucormycosis. Mucormycosis was observed in patients with moderate to severe SARS-CoV-2 infection with a mean HRCT severity score of 14/25. There was no difference in the extent of disease based on the history of hospital admission, oxygen therapy, and steroid intake during COVID treatment, and COVID vaccination, although uncontrolled diabetes showed increased overall disease severity and intracranial disease compared to controlled diabetes.

Management of ROCM consists of surgical debridement of the involved segment supported by the use of liposomal amphotericin and other antifungal therapy. Expedient radiological identification of disease load, the involved structures, and the extent of necrotic tissue is the first step in surgical planning which may consist of turbinectomy, debridement of the involved paranasal sinuses, palatal resection, orbital wall resection, orbital exenteration, and drainage of brain abscess. Contrast-enhanced MRI of the brain, orbits, and paranasal sinus along with MR angiography of intracranial arteries should be the preferred modality to assess the extent of the disease and CT should be reserved for surgical planning as it can underestimate the extent of the disease.

There are few proposed guidelines in the literature for the staging of ROCM which classify it into four stages (i) nasal, (ii) paranasal sinus, (iii) orbital, and (iv) intracranial disease. However, the involvement of these four areas may not necessarily represent the stage of the disease. Our straightforward, checklist-based, anatomical scoring system provides objective means to quantify the extent of involvement.

**Sinonasal involvement adjacent soft tissues**

Although there are no imaging criteria specific for radiological diagnosis of ROCM, presence of bone destruction, vascular invasion, T2 hypointensity, loss of contrast enhancement (black turbinate sign) have been suggested as signs of mucormycosis. The most common signal intensity
Pattern was T2 hyperintense lesions with diffusion restriction and complete or incomplete post-contrast enhancement with areas of LOCE. LOCE can be a radiological surrogate marker to identify tissue ischemia and necrosis and correlates with endoscopic findings in 76% of cases. The radiological report should separately describe the areas with LOCE which must be radically debrided because antifungal treatment will not be effective due to prevention of antifungal entry inadequate concentration through ischemic necrotic barrier.

Orbital involvement

STIR and T1 sequences were the most sensitive sequence to identify the involvement of extraconal, preseptal, and intraconal fat. For evaluation of extraocular muscles, STIR was the most sensitive sequence showing hyperintensity and muscle thickening. The optic nerve in our scoring was assigned a higher score (score of 2) and it is associated with blindness. For assessment of optic nerve, DWI was the most sensitive sequence, whereas STIR and post-contrast images identified superior ophthalmic vein (SOV). Distortion of the globe shape (guitar pick sign) can result due to extensive edema of orbital fat and raised intraorbital pressure which also was assigned a higher score (of 2) in our study.

Cranial involvement

Meningitis, cavernous sinus involvement, and internal carotid artery narrowing, abscesses, infarcts, and cranial nerve involvement were the predominant findings in the brain. The most common imaging appearance of abscesses was ring-enhancing lesions with restriction in the abscess wall and central facilitation as well as blooming artifacts on SWI. Perineural spread and cranial nerve involvement is a known and relatively specific feature of cerebral mucormycosis and can involve II, III, IV, V, and VIth cranial nerve. In our study, cranial nerve involvement was seen in 5 cases all of which showed contrast enhancement, loss of T2 hyperintense signal, and blooming artifacts on SWI, and in one case also involved the exit of the globe shape (guitar pick sign) can result due to extensive edema of orbital fat and raised intraorbital pressure which also was assigned a higher score (of 2) in our study.
zones of the Vth cranial nerve. The involvement of the olfactory nerve, the presence of blooming artifact in the exit zones, and the mucor abscess are the new features observed in our study that has not been previously documented. This may be due to the presence of increased accumulation of hemorrhagic products and paramagnetic materials such as iron, magnesium, and manganese.11

This retrospective study had several limitations. First, the MR severity score assumes that the abnormal signal present on MR is a surrogate for mucor burden; however, there was no histologic confirmation of the findings at each involved area. Second, the MR was assessed by only two radiologists together and the inter-rater agreement could not be assessed. Further studies should focus on the degree of consistency of MR scoring among radiologists with different levels of experience.

To summarize, the present study describes the common and uncommon MRI signs of COVID-associated ROCM. This study provides a straightforward semi-quantitative method for assessing the severity of ROCM. We envision that this MRI severity score can expedite the recognition of patients with severe disease of COVID-associated ROCM.

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