Evaluation of Serial Chest Radiographs of High-Altitude Pulmonary Edema Requiring Medical Evacuation from South Pole Station, Antarctica: From Diagnosis to Recovery

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ABSTRACT

Introduction:

Chest radiography is a diagnostic tool commonly used by medical providers to assess high-altitude pulmonary edema (HAPE). Although HAPE often causes a pattern of pulmonary edema with right lower lung predominance, previous research has shown that there is no single radiographic finding associated with the condition. The majority of research involves a retrospective analysis of chest radiographs taken at the time of HAPE diagnosis. Little is known about the radiographic progression of HAPE during treatment or medical evacuation.

Materials and Methods:

Three sequential chest radiographs were obtained from two patients diagnosed with HAPE at the Amundsen-Scott South Pole Station, Antarctica, who required treatment and medical evacuation. Deidentified and temporally randomized images were reviewed in a blinded fashion by two radiologists. A score of 0 (normal lung) to 4 (alveolar disease) was assigned for each of the four lung quadrants for an aggregate possible score ranging from 0 to 16 for each radiograph.

Results:

Patient 1's initial radiograph showed severe HAPE with an initial score of 13. Despite a rapid clinical improvement after medical evacuation, he continued to show multifocal radiographic evidence of disease in all the lung quadrants on day 1 (score of 11) and day 2 (score of 5). Patient 2's radiographs showed less severe disease at presentation (score of 6). Despite the need for continued treatment, his radiographs showed a rapid improvement, with radiographic score decreasing to 3 on day 1 and 1 on day 3.

Conclusion:

The chest radiographs showed serial improvement after medical evacuation in both patients. There was not a strong correlation between clinical symptoms and radiographic severity in subsequent images.

INTRODUCTION

High-altitude pulmonary edema (HAPE) is a form of non-cardiogenic pulmonary edema associated with an ascent above 2,500 m.[1,2] HAPE is believed to occur as a result of an uneven hypoxic vasoconstriction of the pulmonary capillaries, leading to a rise in pulmonary arterial and capillary pressure. Hypoxia causes endothelial dysfunction, resulting in increased capillary permeability and suppression of endothelium-dependent vasodilation. The combination of hypertension and permeability causes leakage of fluid into the pulmonary interstitium and alveolar spaces.[3,4] Patients may present with mild symptoms such as cough, subjective dyspnea, or radiographic findings of interstitial edema. Severe presentations are associated with high morbidity and mortality and may require costly evacuation to lower altitudes.[5,6]

HAPE can develop at the Amundsen-Scott South Pole Station, an isolated research facility located at 9,300 feet (2,835 m) on the Antarctic plateau. Owing to the global air movements and the Earth's rotation, barometric altitude at the South Pole can be higher than its relative altitude above sea level.[7] Dynamic barometric pressure changes and travel restrictions make acclimatization impractical en route to the Amundsen-Scott South Pole Station, increasing the risk for the development of HAPE.[8] Despite precautionary measures including pre-deployment education and prophylactic acetazolamide, HAPE remains a challenging pathology to treat in the austere, resource-limited environment of the South Pole.[8]

Chest radiography is a diagnostic tool commonly used by medical providers during the initial assessment for HAPE.[9,10] Since the 1970s, a pattern of pulmonary edema

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with right-sided and peripheral predominance has been noted in patients who develop HAPE, although there was significant heterogeneity of appearances on chest radiographs.[11] Multiple studies have also attempted to assess the structural changes on presenting chest radiographs, including cardiac and pulmonary vasculature measurements, with mixed results.[10,12–14]

While there has been a robust discussion of the initial chest radiographic findings in HAPE, there is a paucity of published literature and companion radiographic images that document prospective radiological changes during treatment of and recovery from HAPE in the austere medical setting. The purpose of this manuscript is to review radiographs of two patients medically evacuated from Amundsen-Scott South Pole Station for HAPE from initial diagnosis to clinical improvement.

METHODS

Chest radiographs were obtained from two patients at the Amundsen-Scott South Pole Station, Antarctica (elevation: 2,835 m), and the McMurdo Station, Antarctica (elevation: 183 m), by the Emergency Medicine and Aerospace Medicine physicians after the patients were diagnosed with HAPE. Each image was obtained in the upright, posterior-anterior projection. The images were deidentified and stored for later use after return to the United States.

The images were temporally randomized, anonymized, and reviewed independently by two radiologists (A.J.S. and S.M.B.) on diagnostic workstations. The radiologists both have 4 years of clinical experience. Each chest radiograph was interpreted in the standard fashion and then assessed using the four-quadrant scoring system used to assess HAPE, as described by Vock et al.[10] Using the mediastinum and the hila as the vertical axis and horizontal axis, respectively, the chest was divided into four quadrants. A chest radiograph score ("score") was assigned from 0 to 4 for each quadrant. A score of 0 was given for normal-appearing parenchyma; 1 for questionable pathologic areas of interstitial edema; 2 for undoubted areas of disease that represented <50% of the quadrant; 3 for nonconfluent interstitial disease of >50% of the quadrant; and 4 reflects alveolar/airspace opacification that was further subcategorized as patchy (4a) or confluent (4b). The score for the entire lung was a summation of each regional score, with a possible minimum of 0 to a maximum of 16. Interstitial and airspace abnormalities were then subjectively categorized as either central or peripheral predominant. Day 0 represents the initial date of presentation to medical care and not the date of symptom onset.

Interrater reliability was assessed using Fleiss' kappa coefficient. Initial discrepancies between the two reviewers were reassessed by both physicians, and a consensus was obtained. Statistical analysis was performed using a commercial software (STATA version 14.0; Stata Corp., College Station, TX, USA).

TABLE I. Objective Radiologist Evaluation and Scoring of Sequential Chest Radiographs of Patient 1 and Patient 2 Using the Scoring System by Vock et al.[10] A Score was Assigned from 0 to 4 for Each Lung Quadrant. A Score of 4 Reflects Alveolar/Airspace Opacification Which was Further Subcategorized as Patchy (4a) or Diffuse (4b). An Aggregate Possible Score of 0 to 16 is Provided for Each Image

	Location	Day 0	Day 1	Day 2
Patient 1	Upper right	4a	4a	1
	Upper left	4a	2	2
	Lower right	4b	4a	1
	Lower left	1	1	1
	Total image	13	11	5
	Location	Day 0	Day 1	Day 3
Patient 2	Upper right	0	1	0
	Upper left	1	0	0
	Lower right	4a	2	1
	Lower left	1	0	0
	Total image	6	3	1

RESULTS

Radiologic assessment of the serial chest radiographs is presented in Table I. An initial Cohen's kappa coefficient of 0.67 [95% CI for free-marginal kappa (0.45, 0.89)] was measured between the two reviewers. A brief history is provided for each patient. Additional, detailed patient history is provided in Rose et al.[8]

Patient 1 is a 23-year-old male with no significant medical history who presented with progressively worsening shortness of breath and headache that began 3 days before evaluation. He was noncompliant with prophylactic medications. On initial examination, the patient was in acute respiratory distress, appeared cyanotic, and had bilateral wheezes and crackles that were more pronounced in the right chest. The patient had initial oxygen saturation of 49%, a pulse of 120, and a respiratory rate of 36 breaths/minute (bpm). He was provided 15 L/min oxygen by nonrebreather mask, improving his oxygen saturation to 95%. He was administered nifedipine 30 mg, acetazolamide 250 mg, dexamethasone 4 mg, ibuprofen 600 mg, and 2 L of lactated Ringer's solution. He remained at the South Pole Station for 6 hours before medical evacuation to the McMurdo Station. He had continued, rapid improvement during medical evacuation and was discharged for continued observation upon arrival at the McMurdo Station.

Patient 1 had a chest radiograph performed on day 0 at the South Pole Station and two radiographs on day 1 and day 2 at the McMurdo Station after medical evacuation (Fig. 1). The patient's initial chest radiograph showed severe, right greater than left mixed interstitial and alveolar opacities consistent with pulmonary edema. Despite rapid clinical improvement in Patient 1's symptoms with treatment, his radiograph showed persistent disease, out of proportion to clinical symptoms, with only a 16% score improvement (11 from 13) after

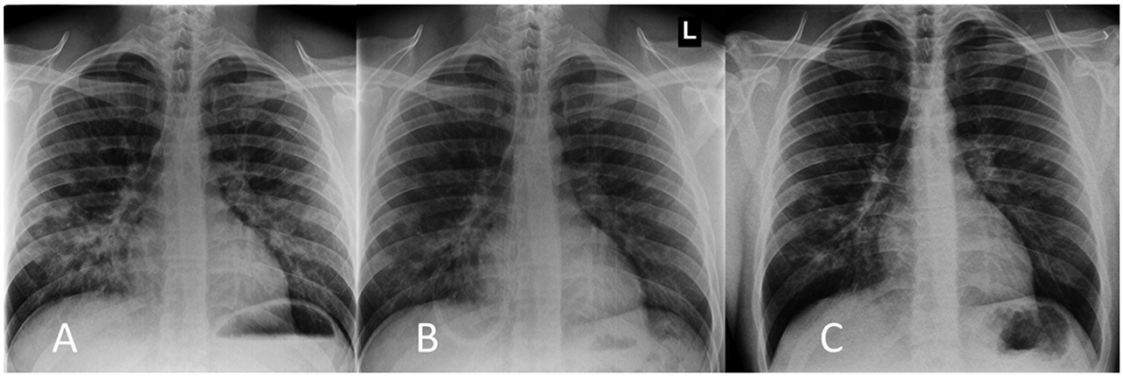

FIGURE 1. Sequential anterior-posterior chest radiographs of Patient 1, a 23-year-old male, with high-altitude pulmonary edema (HAPE) on (A) day 0, (B) day 1, and (C) day 2.

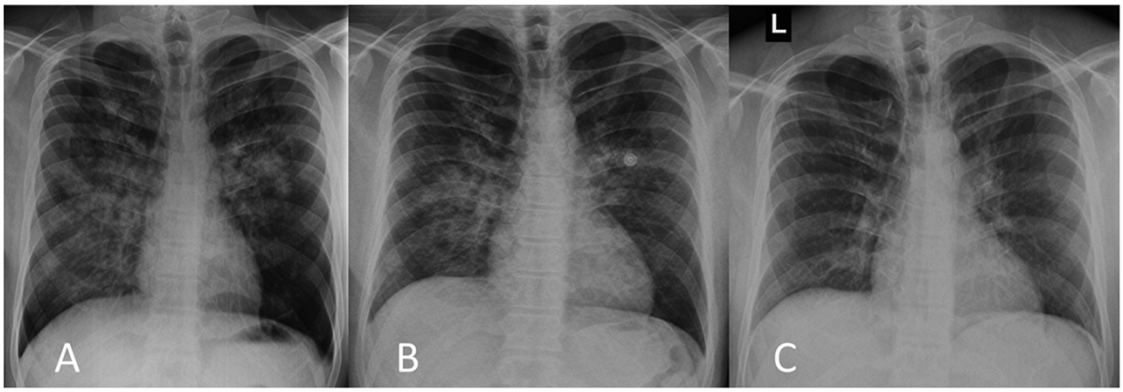

FIGURE 2. Sequential anterior-posterior chest radiographs of Patient 2, a 40-year-old male, with high-altitude pulmonary edema (HAPE) on (A) day 0, (B) day 1, and (C) day 3. Of note, the anatomical side marker is incorrectly placed on image C and the image is correctly oriented.

approximately 24 hours (day 1). By day 2, he continued to show possible disease in all the four lung quadrants.

Patient 2 is a 40-year-old male with no significant medical history who presented with shortness of breath 5 days after arrival at the South Pole. The patient's dyspnea began after completing a strenuous workout and progressively worsened over a 36-hour period before medical evaluation. He was noncompliant with prophylactic medications. On initial examination, the patient was in acute respiratory distress, had difficulty speaking, and had bilateral rales that were more pronounced in the right chest. The patient had an initial oxygen saturation of 41%, a pulse of 142, and a respiratory rate of 32 bpm. He was initially provided 6 L/min oxygen by nasal cannula, which improved his oxygen saturation to only 71%. Subsequent 15 L/min oxygen by a nonrebreather mask increased his oxygen saturation to 93%. Physicians administered nifedipine 20 mg, acetazolamide 250 mg, and 1.5 L of lactated Ringer's solution. The patient was medically evacuated to the McMurdo Station where he remained symptomatic and required 2 L oxygen by nasal cannula overnight. Nifedipine 20 mg every 8 h was continued for the next 2 days.

Patient 2 had a chest radiograph performed on day 0 at the South Pole Station and two radiographs on day 1 and day 3 at the McMurdo Station after medical evacuation (Fig. 2). Patient 2's initial chest radiographs showed right greater than left lower lung interstitial and mild patchy alveolar opacities consistent with pulmonary edema. After approximately 24 hours, Patient 2 had a 50% interval improvement in his radiograph score (3 from 6), but continued to require oxygen supplementation.

Both patients had marked improvement in chest radiograph by 48 to 72 hours after initial presentation.

DISCUSSION

This study sought to provide longitudinal evaluation of the radiologic changes in patients that developed HAPE in an austere, resource-limited setting from presentation through symptom resolution. We provide the serial images of two patients who developed life-threatening HAPE while at the South Pole Station, requiring emergent medical evacuation. The initial radiographs in our study showed alveolar airway opacification with right lower quadrant involvement, consistent with the "classic findings" of HAPE. The two patients in our study showed a dichotomous response during serial radiographic evaluation. Patient 1 showed rapid clinical

improvement after medical evacuation and treatment. However, he presented with more severe radiographic findings which remained visible on repeat radiographs.

Prior research of the initial presentation of HAPE on chest radiographic has found that radiographic findings are generally worse in the lung bases, typically the right lower quadrant, with peripherally located homogenous airspace disease.[9] However, in the same cohort, there were marked differences in appearance of the edema, with 55% of participants having nonconfluent and interstitial edema and 33% of patients having partially confluent edema. Edema was noted to be bilateral in six of nine patients (66%), but unilateral in two patients (one on the right and one on the left).[9] In a study where chest radiographs with recurrent HAPE were compared to case-matched controls, there were no recurrent features in those with recurrent disease. Approximately half of the patients had different morphological appearance or distribution of edema during relapses.[10] Given this possible morphologic variability, it is unsurprising that we did not find a classic peripheral predominance of edema.

While there is significant literature documenting the initial changes in chest radiographs in HAPE, few studies have assessed subsequent radiographic change and provided companion radiographic images during treatment and recovery. In a study by Vock et al., chest radiographs were assessed serially between onset and 10 days of symptoms in 60 patients. A slow, progressive improvement was noted in the cohort with repeat images, despite many being lost of follow-up.[10] Patients had an approximately 18% improvement in objectively graded HAPE in the first 24 hours with some patients continuing to show significant radiologic pathology up to 10 days.[10]

Two studies have retrospectively assessed chest radiographs at both admission and discharge. These studies sought to evaluate possible interval structural changes, such as pulmonary artery diameter or cardiothoracic ratio, to help elucidate underlying pathophysiologic causes of HAPE. For example, Koizumi et al. found that during initial presentations of HAPE, patients have slight enlargement of their cardiothoracic ratio, especially of the right ventricle.[12] However, the retrospective assessment of structural abnormalities is difficult to clinically correlate and has mixed findings between studies. These studies published no sequential clinical images and compared radiographs at admission and after a full recovery rather than over the course of clinical improvement.

In our study, there was improvement in the radiographs of both patients with time. However, there was limited correlation with clinical symptoms and radiographic severity. For physicians and radiologists practicing in both high-resource and austere settings, clinical evaluation of vitals, subjective work of breathing, changes in pulmonary auscultation, and bedside ultrasonography[15] may be more reliable real-time indicators of a patient's clinical improvement or deterioration than serial chest radiographs. Notably, however, neither patient's radiographs in our study showed interval worsening after medical evacuation. We believe this is clinically relevant information. In a case of interval worsening of chest radiographs after medical evacuation, physicians should immediately consider worsening HAPE or a separate pathologic etiology such as multifocal infection or cardiogenic pulmonary edema.

Although we believe these chest radiographs provide unique clinical information, it is possible that assessment was limited by image quality. Owing to the limited resources in Antarctica and restrictions on protected health information from the National Science Foundation, image format was restricted to JPEG/TIFF during export and evaluation. Therefore, the blinded radiologists were unable to perform a more detailed assessment, including measurements of cardiovascular and pulmonary structures. Although it was unlikely to impact our results, we cannot comment on the structural changes assessed by previous researchers. Although our study involved two radiologists blinded to patient identification and the temporal sequence of the images, they were not blinded to the diagnosis of HAPE which is a possible source of bias during their assessment. Given our small sample size of two participants and the uncommon occurrence of HAPE in Antarctica, it is possible that variable pathology and radiographic appearance would have been noted with different or additional participants. Furthermore, the images were obtained at separate locations and show variation in the extent of breath-hold, which could confound radiologist interpretation. Despite these limitations, we believe this information is unique and provides valuable insight into the longitudinal changes of chest radiographs during medical evacuation and treatment of HAPE.

CONCLUSION

In this study, sequential chest radiographs were evaluated from two patients who were medically evacuated from the Amundsen-Scott South Pole Station, Antarctica after development of severe symptomatic HAPE. The chest radiographs showed serial improvement after medical evacuation in both patients, although radiographic changes lagged behind clinical improvement. Radiographic progression following evacuation to low altitude should raise clinical suspicion for worsening HAPE and/or an alternative etiology for the patient's clinical presentation.

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CONFLICTS OF INTEREST

No authors have a conflict of interest to report.

AUTHOR CONTRIBUTIONS

Study concept and design (C.D.N., J.S.R.); acquisition of the data (J.S.R.); analysis of the data (C.D.N., A.J.S., S.M.B., J.S.R.); drafting of the manuscript (C.D.N.); critical revision of the manuscript (C.D.N., A.J.S., S.M.B., J.S.R.); and approval of final manuscript (C.D.N., A.J.S., S.M.B., J.S.R.).

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