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Case series: Adolescent victims of the vaping public health crisis with pulmonary complications

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Abstract

Alongside the epidemic use of electronic cigarettes (e-cigarettes) across the country, evidence of multiple pulmonary complications has emerged, with the most immediately life-threatening being the new clinical condition of e-cigarette/vaping-associated lung injury (EVALI), with investigation actively underway to further define this entity and determine the cause or causes. We present a series of cases of respiratory illnesses associated with e-cigarette use, many of which meet criteria for suspected or confirmed EVALI, managed at a pediatric tertiary care center, demonstrating notable variation in presenting symptoms and severity. Most cases improved with supportive respiratory care and the administration of corticosteroids and antibiotics, although generally no infection was found. The cases also tend to show improvement with discontinuation of the use of e-cigarettes. We discuss challenges in determining the contribution of e-cigarettes to the case pathology and review possible diagnostic and treatment options. In patients suffering from e-cigarette-related respiratory illness including EVALI, the primary treatment goal should be the cessation of e-cigarette use and avoidance of other possible pulmonary toxins, including conventional cigarettes. Prevention of e-cigarette use is critical in the youth population, as these patients are typically nicotine naïve and do not engage in smoking conventional cigarettes before initiation of vaping.

KEYWORDS

electronic cigarettes, EVALI, nicotine, THC, vaping-associated lung injury

1 | INTRODUCTION

The use of electronic cigarettes (e-cigarettes) has exploded among middle and high school students in the USA.[1] This behavior, known as "vaping," involves aerosolization of a complex chemical mixture, often containing nicotine or tetrahydrocannabinol for inhalation, using an electronic heating element. The purported safety of e-cigarettes touted by manufacturers contrasts sharply with the emerging harmful pulmonary and extrapulmonary effects.

Vaping is highly prevalent among adolescents, with 25% of high school seniors reporting vaping in the past month and 12% reporting daily use in 2019.[2] The recent observation of pulmonary complications associated with vaping (including chronic cough/bronchitis symptoms,[3,4] increased asthma morbidity,[5,6] and e-cigarette/vaping-associated lung injury [EVALI][7]) demonstrates that vaping carries considerable pulmonary risks. Adolescents and young adults may be uniquely susceptible to pulmonary injury following e-cigarette use, whether related to increased uptake or ongoing lung development, with a median age of 19 in the largest case series of pulmonary illness related to e-cigarette use to date,[7] indicating that there may be unique susceptibilities to lung injury from e-cigarette use in adolescents and young adults. In this report, we describe 10 cases of lung illness

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and worsening respiratory status associated with e-cigarette use from a tertiary care pediatric hospital (Table 1). Nine of these cases presented between April 2019 and January 2020, and one presented May 2018. We present four representative cases of more severe injury in further detail.

2 | CASE 1

A 17-year-old male with depression presented with fever, cough, emesis, and chest pain. He used e-cigarettes since middle school, with recent use described as "near-constant." He consumed nicotine and marijuana e-cigarettes with a variety of flavors purchased from online vendors. After 6 days of illness, he sought medical attention for shortness of breath and was prescribed azithromycin for presumed atypical pneumonia. He continued to worsen, and on day 10 of illness presented with hypoxia to 86% in room air. Chest X-ray (CXR) showed multifocal opacities. His laboratory values are shown in Table 1. He was initiated on ceftriaxone then broadened to levofloxacin. Chest computed tomography (CT) on hospital day 3 demonstrated bilateral ground-glass appearance in a "bat wing" distribution (Figure 1). He required escalating respiratory support to a maximum of 25 L high-flow nasal cannula, with a fraction of inspired oxygen of 40%. Bronchoalveolar lavage (BAL) revealed 15% to 19% eosinophils. He improved after receiving prednisone for presumed acute eosinophilic pneumonia. He was discharged on hospital day 9, and has completed an 8-week prednisone wean during which his symptoms and pulmonary function testings (PFTs) were monitored closely. He has resumed vaping since discharge and was referred to our hospital's adolescent substance abuse program. Although currently asymptomatic, he has abnormal diffusion capacity that has worsened with decreasing steroid dosing and restarting vaping.

3 | CASE 2

A 16-year-old male with dry cough for months developed several days of general malaise, decreased appetite, chills, and fever to 103°F. The patient reported vaping. Initially diagnosed with a viral illness, his worsening cough and shortness of breath led to an evaluation in the Emergency Department. He was ultimately intubated for worsening respiratory failure and acute respiratory distress syndrome. He received linezolid, azithromycin, meropenem, and intravenous methylprednisolone. His respiratory failure improved, leading to extubation on hospital day 14. Infectious studies demonstrated no growth (Table 1). He was discharged in room air after a 23-day hospitalization without antibiotics or steroids. PFT at follow-up 2 months post original presentation shows forced vital capacity 80%, forced expiratory volume in 1 second 85%, total lung capacity 84%, and mildly reduced diffusing capacity of the lung for carbon monoxide at 69% predicted. In addition, he had mild hypoxia with exercise with a peripheral oxygen saturation of 95% in room air. Further evaluation is planned.

4 | CASE 3

A 16-year-old male with a history of polysubstance abuse who resides in a rehabilitation facility due to a history of intentional overdose presented with 2 days fluctuating temperatures, headaches, nausea, shortness of breath, and the sensation of not being able to take in breaths. He reported increasing frequency of smoking cigarettes and vaping in the days before presentation. In the Emergency Department, he received nasal cannula oxygen for hypoxia of 88%. CXR showed prominence of interstitial markings, small pleural effusions, and peripheral ground-glass opacities. A chest CT showed scattered patchy ground-glass opacities predominantly in subpleural location, smooth interlobular interstitial thickening, small bilateral pleural effusions, as well as 2 and 3 mm nodules (Figure 2). He received ceftriaxone and azithromycin but infectious studies remained negative. He received a 14-day prednisone course with a wean off over 8 weeks. PFT off steroids was normal except for mild to moderately reduced diffusion capacity (56% predicted corrected). Unfortunately, he resumed smoking and vaping on discharge to his rehabilitation facility and was referred to our hospital's adolescent substance abuse program.

5 | CASE 4

A 19-year-old male with asthma, atrial fibrillation, epilepsy, and polysubstance use presented to the emergency room (ER) after he was found unconscious. He reported a cough for 6 months with weekly episodes of blood-tinged sputum. He reported vaping multiple times per day since age 15. He used Juul brand nicotine e-cigarettes with mango flavoring, tetrahydrocannabinol (THC) cartridges and butane prepped hash with hash oils. He also smoked cigarettes. In the ER, his oxygen saturation was 78%, and he was admitted to the MICU on high-flow nasal cannula. CXR showed bilateral opacities and chest CT demonstrated ground-glass opacities (Figure 4). He was intermittently febrile and received vancomycin, ceftriaxone, and azithromycin, ultimately narrowed to ampicillin/sulbactam for concern for aspiration. Infectious studies were negative apart from a fungal respiratory culture growing *Candida albicans*. He was discharged on amoxicillin/clavulanic acid to complete treatment for presumed pneumonia. At time of discharge, he had a productive cough without further episodes of hemoptysis. He was readmitted 2 months later after he was found unresponsive in the setting of substance use, with one episode of hemoptysis though denied continued vaping. BAL revealed 90% macrophages containing brown pigment, and infectious studies have been negative. Repeat CT scan showed significant improvement in prior abnormalities but remained abnormal.

The remaining cases are detailed in Table 1.

6 | DISCUSSION

We report a spectrum of clinical findings including profound respiratory failure with hypoxia, presumed worsening of underlying lung disease, and chronic symptoms with normal imaging and PFTs in adolescents who used vaping products. Some of these patients (Case 1-8), meet the Centers for Disease Control and Prevention's (CDC) surveillance case definition of EVALI, as follows: (a) use of an e-cigarette or dabbing in 90 days before symptom onset, (b) pulmonary infiltrate, such as opacities, on chest X-ray or ground-glass opacities on chest CT, (c) the absence of pulmonary infection on initial workup, and (d) no evidence in the medical record of alternative plausible diagnosis.[8] Despite the correlation of vaping with respiratory illness, the precise causative chemical agents in EVALI remain undefined. Adding to the complexity of determining causation are (a) the different vaping compositions used by patients; (b) reluctance of manufacturers to disclose the exact chemical composition of their vaping products; (c) "grey market" vaping products, sold via informal means not authorized by the primary manufacturer such as through social media, that are then modified by the addition of different chemicals; (d) that vaping may pyrolysis chemicals in the vaping fluid to produce a new chemical milieu with its own unique toxicity; and (e) very little, if any, safety testing of vaping products that have been reported in the literature. Furthermore, the host factors that contribute to EVALI have yet to be described. Regardless of this uncertainty, eight of the patients in our series meet the CDC's surveillance case definitions for confirmed or probable events.[7] We have included two patients who do not meet CDC criteria to demonstrate the full range of pulmonary manifestations we have observed in adolescents who vape.

Our 10 cases reveal the spectrum of respiratory symptoms ranging from the cough that resolves with discontinuation of e-cigarettes to hypoxic respiratory failure requiring prolonged intensive care. While not all 10 cases meet criteria for confirmed or probable cases of EVALI (eg, case 10 has normal imaging), overall, the cases demonstrate concerning respiratory manifestations presented in adolescent patients who are using vaping products. Due to the wide range of products used and clinical manifestations in these patients, it is challenging to determine the contribution that vaping practices had on the development of the respiratory issues. To better understand this contribution, we must become accustomed to eliciting a thorough history of vaping practices in adolescents and young adults.

Case 1 and 7 expand the clinical experience with acute eosinophilic pneumonia secondary to e-cigarette use.[9,10] In general, patients with eosinophilic pneumonia describe nonspecific symptoms including cough, dyspnea, and fever.[11,12] Interestingly, eosinophilic pneumonia did not predominate in other cohorts with vaping injury, suggesting that host or drug-related factors contribute to this illness.[7] In addition, the imaging findings in Case 1 were not classic for eosinophilic pneumonia, which tends to have a random or peripheral distribution of opacification as opposed to a centralized "bat wing" distribution. Similarly, Case 2, with acute respiratory distress syndrome (ARDS), adds to a number of reported cases of ARDS in the setting of vaping.[7,11] Case 9 demonstrates that vaping may potentially worsen manifestations of underlying chronic suppurative lung diseases, leading to acute on chronic worsening of symptoms.

We now have a Vaping clinic at our center and continue to see 2 to 3 new patients per week for evaluation of vaping-related pulmonary symptoms. There are currently 83 patients at various stages of evaluation followed through this program. This case series represents the initial group of patients in which we believe vaping likely contributed to the development of observed respiratory manifestations. Poor awareness of the emerging respiratory complications of vaping may have contributed to under-reporting of cases, especially since clinical features overlap with common respiratory illnesses, and we strongly suspect that many patients have not been asked about vaping practices.

While some patients present with respiratory failure, a substantial proportion of patients, including some in our series, develop less severe and chronic symptoms. These patients may present to inpatient or outpatient settings with nausea, emesis, fevers, prolonged cough, and difficulty breathing without signs of acute respiratory distress or hypoxia. Notably, the presence of positive infectious studies does not preclude lung damage due to e-cigarette use. As was demonstrated in our cohort, patients tend to have elevated inflammatory markers including C-reactive protein and erythrocyte sedimentation rate, and many also have leukocytosis. Plain and cross-sectional imaging yield highly variable results that range from initially normal chest imaging to mild airspace disease to extensive multifocal opacities in varying patterns. The paucity of knowledge regarding e-cigarette-associated lung injury coupled with the unknown safety of these products impels a thorough pulmonary evaluation in vaping patients with respiratory complaints.

Based on CDC recommendation and experience in our center, we recommend the following: (a) obtaining a thorough and confidential history about use of e-cigarettes, including substances and devices used, their source, and the method of use; (b) evaluating for infectious etiologies using sputum and nasopharyngeal specimens, with bronchoscopy with BAL in severe or persistent cases or when less invasive samples cannot be obtained or are unrevealing; (c) CXR (or chest CT if diffuse findings are found on plain films or if CXR findings do not account for clinical presentation); and (d) pulmonary function tests including spirometry, lung volumes, diffusion capacity, and 6 minute walk test.[13] Any adolescent reporting e-cigarette use with respiratory symptoms merits referral to a pediatric pulmonologist for further evaluation. Based on our experience, treatment primarily involves supportive care; many patients respond to steroids, but the most important treatment is the cessation of e-cigarette use. The CDC recommends admission for patients with oxygen saturation less than 95% and/or respiratory distress and follow-up ideally within 48 hours after discharge. For outpatients, the CDC recommends follow-up in 24 to 48 hours as the presentation can rapidly evolve.[14]

Vaping-related severe pulmonary injury/EVALI is a serious public health concern. Social pressures have been increasing for

TABLE 1 Case demographics, clinical course, laboratory, and imaging findings

Case	Demographics: Age, y Gender Medical history	Vaping history	Presenting features	Maximal respiratory support	Treatment and length of hospital stay (LOS)	Salient noninfectious laboratory findings	Infectious laboratory findings (unless indicated (studies negative)	Imaging findings	Bronchoscopy findings	Meets CDC criteria for EVALI
Case 1	17 Male Depression	Substances used: nicotine and tetrahydrocannabinol (THC) Flavoring: yes Frequency of use: "near constant"	Symptoms: productive cough, hemoptysis, fever, shortness of breath, rhinorrhea, nausea, vomiting, and diarrhea Initial oxygen saturation: 86%	High-flow nasal cannula (maximum flow 25 L/min)	Antibiotics: yes Steroids: prolonged prednisone wean (total 8 wk duration) LOS: 9 d	White blood cell count (WBC) 8.6 C-reactive protein (CRP) 25.4	All viral, bacterial, and fungal studies negative	CXR: multifocal opacities Chest CT: bilateral ground-glass opacification in "bat wing" configuration (Figure 1)	Predominance of granulocytes (75%), including 20% to 25% of which are eosinophils, 15% macrophages, and 10% respiratory epithelial cells	Yes
Case 2	16 Male Appendicitis s/p surgical intervention	Substances used: unknown Flavoring: unknown Frequency of use: "on and off for one year" Patient has been guarded in discussions about use.	Symptoms: fever, nasal congestion, vomiting, and decreased oral intake Initial oxygen saturation: 93%	Intubation, 10 d (maximum settings 38/14, rate 20); extubated to high-flow nasal cannula, 2 d (maximum flow rate 30 L/min); low flow nasal cannula for 9 d (maximum 5 L)	Antibiotics: yes Steroids: IV methylprednisolone for 7 d LOS: 23 d	WBC 13.4 CRP 40.63; procalcitonin 0.51 VBG 7.44/59.5/25	All viral, bacterial, and fungal studies negative	CXR: multifocal consolidative opacities	N/A	Yes

(Continues)

TABLE 1 (Continued)

Case	Demographics: Age, y Gender Medical history	Vaping history	Presenting features	Maximal respiratory support	Treatment and length of hospital stay (LOS)	Salient noninfectious laboratory findings	Infectious laboratory findings (unless indicated (studies negative)	Imaging findings	Bronchoscopy findings	Meets CDC criteria for EVALI
Case 3	16 Male Acne, depression, polysubstance abuse, suicidal ideation, remote history of asthma, seasonal allergies, and gastroesophageal reflux	Substances used: mostly nicotine, some THC Flavoring: yes Frequency of use: 1 Juul pod per day for several months	Symptoms: fluctuating temperature, headache, nausea, visual changes, difficulty with inspiration Initial oxygen saturation: 95% (with subsequent desaturation to 88% in the Emergency Department)	Nasal cannula (maximum 3 liters)	Antibiotics: yes Steroids: prednisone for 14 d LOS: 5 d	WBC 22.1 Procalcitonin 0.38 Antineutrophil cytoplasmic antibodies (ANCA)-borderline with C-ANCA staining pattern; borderline for presence of antibodies to proteinase	All viral and bacterial studies negative	CXR: Prominence of interstitial markings, small pleural effusions, and peripheral ground-glass opacities Chest CT: scattered patchy ground-glass opacities, predominantly in subpleural location, smooth interlobular interstitial thickening, small bilateral pleural effusions, and small nodules (Figure 2)	N/A	Yes
Case 4	19 Male	Substances used: nicotine and THC Flavoring: unknown	Symptoms: "Found down" on bathroom floor. Increased	High-flow nasal cannula (maximum flow 35 liters/minute)	Antibiotics: yes Steroids: no	WBC 8.9 CRP 2.28 VBG 7.34/52.4/28	Fungal culture with *candida albicans*	CXR: bilateral opacities, right greater than left	Sequential BAL aliquots became increasingly gray with soot-like material.	Yes

TABLE 1 (Continued)

Case	Demographics: Age, y Gender Medical history	Vaping history	Presenting features	Maximal respiratory support	Treatment and length of hospital stay (LOS)	Salient noninfectious laboratory findings	Infectious laboratory findings (unless indicated (studies negative)	Imaging findings	Bronchoscopy findings	Meets CDC criteria for EVALI
			work of breathing and worsening cough in setting of 6 mo of cough and 8 wk of hemoptysis			Urine cannabinoids positive			90% macrophages, numerous containing brown pigment. Iron stain with moderately increased numbers of siderophages. Likely mildly increased numbers of lipid-laden macrophages. Infectious studies negative to date	
	Atrial fibrillation, asthma, anxiety, depression, epilepsy, and substance use	Frequency of use: unknown	Initial oxygen saturation: 78%		LOS:7 d	Sweat test negative	All other viral, bacterial, and fungal studies negative	Chest CT: extensive, multifocal airspace and ground-glass opacities (Figure 3)		
Case 5	16 Male	Substances used: unknown Flavoring: unknown	Symptoms: fevers, nausea, vomiting, diarrhea	Nasal cannula (maximum 1 L)	Antibiotics: yes Steroids: no	WBC 4.4 CRP 4.56; procalcitonin 0.84	All bacterial and fungal cultures negative	CXR: left lower lobe (LLL) pneumonia with associated pleural effusion	BAL with 75% macrophages, 5% neutrophils. Mild increase in iron-laden macrophages. Mild increase in fat-laden macrophages. Fungal culture grew scopulariopsis species not thought to be pathogenic	Yes
	Allergy-induced asthma, delayed puberty, small stature, renal diverticulum, and penile adhesions	Frequency of use: up to 3 times a week for 2 y	Initial oxygen saturation: 96%		LOS: 8 d	Sweat test indeterminate		Chest CT obtained 9 mo after initial presentation: Tree-in-bud opacities in the LLL, air-trapping, subsegmental		

(Continues)

TABLE 1 (Continued)

Case	Demographics: Age, y Gender Medical history	Vaping history	Presenting features	Maximal respiratory support	Treatment and length of hospital stay (LOS)	Salient noninfectious laboratory findings	Infectious laboratory findings (unless indicated (studies negative)	Imaging findings	Bronchoscopy findings	Meets CDC criteria for EVALI
								bronchiectasis in upper segment of LLL (site of previous pneumonia) (Figure 4)		
Case 6	14 Female Asthma	Substances used: nicotine Flavoring: unknown Frequency of use: daily for 1 y	Symptoms: difficulty breathing, shortness of breath, nausea, emesis, and chest pain Initial oxygen saturation: 89%	Nasal cannula (maximum 1 L)	Antibiotics: yes Steroids: prednisone for 5 d LOS: 5 d	WBC 20.4 CRP 5.9; procalcitonin 0.15. Urine cannabinoids positive	All viral, bacterial, and fungal studies negative	CXR: large lung volumes, increased perihilar lung markings (asthma vs bronchiolitis).	N/A	Yes
Case 7	17 Male Asthma	Substances used: Juul and THC via Dab Flavoring: yes Frequency of Use: Once a month – once a week for 2 y	Symptoms: chest tightness, cough, and sputum production (with blood-tinged sputum) Initial oxygen saturation: 92%	Nasal cannula (maximum 1.5 L)	Antibiotics: Yes Steroids: prolonged prednisone wean (ongoing at present) LOS: 9 d	WBC 20.4 CRP 0.08; ESR 8	Mycoplasma IgM 0.82 (high), Mycoplasma IgG 0.87 (high), mycoplasma PCR not detected All other bacterial, viral, and fungal studies negative	CXR: normal Chest CT: focal areas of ground-glass opacities in right lower lobe with scattered patchy/nodular	BAL with 72% macrophages, 4% neutrophils, and 2% eosinophils. Transbronchial biopsy with scattered interstitial eosinophils	Yes

TABLE 1 (Continued)

Case	Demographics: Age, y Gender Medical history	Vaping history	Presenting features	Maximal respiratory support	Treatment and length of hospital stay (LOS)	Salient noninfectious laboratory findings	Infectious laboratory findings (unless indicated (studies negative)	Imaging findings	Bronchoscopy findings	Meets CDC criteria for EVALI
								areas of ground-glass and tree-in-bud opacities in the bilateral lower lobes. Moderate diffuse bronchial wall thickening (Figure 5)		
Case 8	18 Female Allergic rhinitis, exercise-induced asthma, anxiety, attention deficit hyperactivity disorder, and autism	Substances used: Juul, THC from dab pen, Eon and Puff Flavoring: yes Frequency of use: Intermittent for 2-3 y, frequency increased to multiple times per day leading to development of symptoms	Symptoms: cough, shortness of breath, chest pain, throat pain, fatigue, nausea, diarrhea, chills, headache, weight loss, and night sweats Initial oxygen saturation: 98%	None	Antibiotics: yes Steroids: no LOS: n/a	WBC 6.8 CRP 0.04; ESR 7 Urine cannabinoids positive	All viral, bacterial, and fungal studies negative	Chest CT: nodular tree-in-bud and ground-glass opacities, mostly in the lingula (Figure 6)	N/A	Yes

(Continues)

TABLE 1 (Continued)

Case	Demographics: Age, y Gender Medical history	Vaping history	Presenting features	Maximal respiratory support	Treatment and length of hospital stay (LOS)	Salient noninfectious laboratory findings	Infectious laboratory findings (unless indicated (studies negative)	Imaging findings	Bronchoscopy findings	Meets CDC criteria for EVALI
Case 9	18	Substances used: nicotine and THC	Symptoms: cough, night sweats, unintentional weight loss	None	Antibiotics: yes	WBC 6.9	AFB culture with *Mycobacterium avium*; respiratory culture with *Staphylococcus aureus*; *Mycoplasma* IgG and IgM elevated but not detected on BAL	CXR: the presence of cavitary lesion	Significant purulent secretions in upper lobes. 75% neutrophils, 12% macrophages, 7% respiratory epithelial cells, and 6% eosinophils. Occasional acid-fast bacilli on AFB stain. Lipid is mildly to moderately increased within macrophages.	No
	Female	Flavoring: yes			Steroids: no	CRP 1.22; erythrocyte sedimentation rate (ESR) 10	1,3-B-D-glucan elevated			
	Recurrent pneumonia, recurrent strep pharyngitis, mild intermittent asthma, positive newborn screen for cystic fibrosis with indeterminate sweat testing, bicuspid aortic valve, and supraventricular tachycardia	Frequency of use: up to 5 times daily for the past year	Initial oxygen saturation: 100%		LOS:3 d	CFTR pathogenic variant c.1521_1523-del led to diagnosis of CFTR-related disease. Variant of uncertain significance associated with autosomal recessive primary ciliary dyskinesia	All other viral, bacterial, and fungal studies negative	Chest CT: apical predominant bronchiectasis with bronchial wall thickening, tree-in-bud nodularity with pulmonary nodules, some with cavitation (Figure 7)		

TABLE 1 (Continued)

Case	Demographics: Age, y Gender Medical history	Vaping history	Presenting features	Maximal respiratory support	Treatment and length of hospital stay (LOS)	Salient noninfectious laboratory findings	Infectious laboratory findings (unless indicated (studies negative)	Imaging findings	Bronchoscopy findings	Meets CDC criteria for EVALI
Case 10	15 Female Possible asthma, chronic joint pain treated with methotrexate, sinopulmonary infections	Substances used: Juul and mod device, unknown brand Flavoring: yes Frequency of use: Rare personal use, but frequent exposure to the "hotboxing" practice of filling a closed space (car) with nicotine vaping exhalant	Symptoms: cough (daytime and night-time), shortness of breath, and sputum production Initial oxygen saturation: 100%	None	Antibiotics: yes Steroids: prednisone for 5 d LOS: N/A	WBC 6.9 CRP 0.27; ESR 20	All viral, bacterial, and fungal studies negative	CXR: normal Chest CT: normal (Figure 8)	BAL with 90% macrophages, 5% ciliated epithelial cells, 1% lymphocytes. Variable weak to strong, overall moderate lipid uptake in 30% of macrophages	No

Abbreviations: AFB, acid-fast bacteria; BAL, bronchoalveolar lavage; CDC, Centers for Disease Control and Prevention; CT, computed tomography; CFTR, cystic fibrosis transmembrane conductance regulator; CXR, Chest X-ray; EVALI, e-cigarette/vaping-associated lung injury; PCR, polymerase chain reaction; WBC, white blood cell.

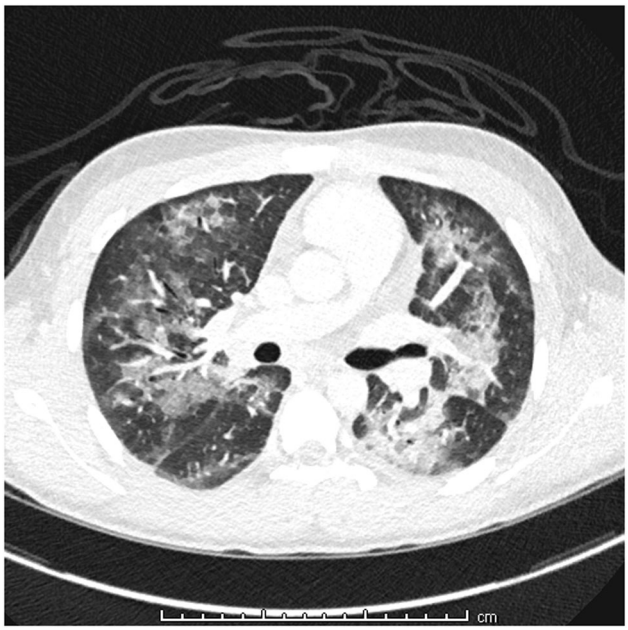

FIGURE 1 Case 1, chest CT: bilateral ground-glass opacification in "bat wing" configuration. CT, computed tomography

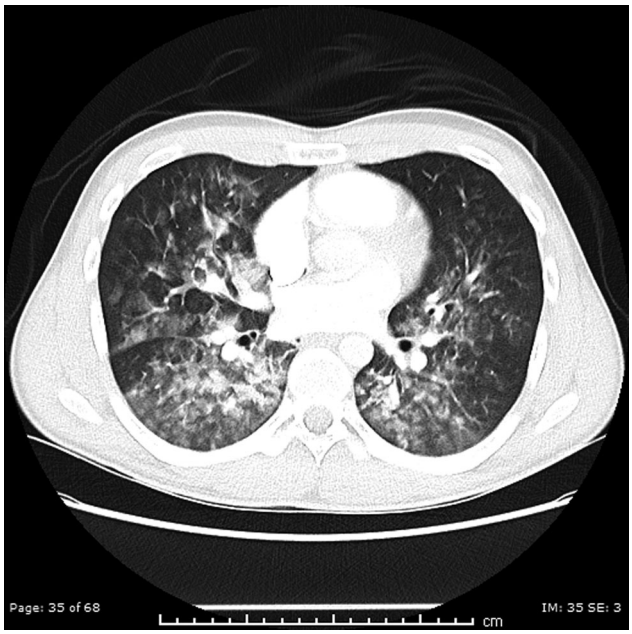

FIGURE 3 Case 4, chest CT: extensive ground-glass opacities. CT, computed tomography

adolescents to initiate e-cigarette use, including the influence of social media and aggressive advertising campaigns. Especially problematic has been the wide availability of these products to minors,[15,16] the addition of flavors intended to promote uptake by youths,[17] the unique addiction potential of e-cigarettes, the lack of safety data in any population,[18] and the marketing of vaping products as lacking adverse health effects.[19] That several members of our cohort continue to use e-cigarettes despite life-threatening lung injury further highlights the potential of vaping products to induce compulsive use. The co-occurrence of mental health disorders with vaping behavior also warrants further evaluation.

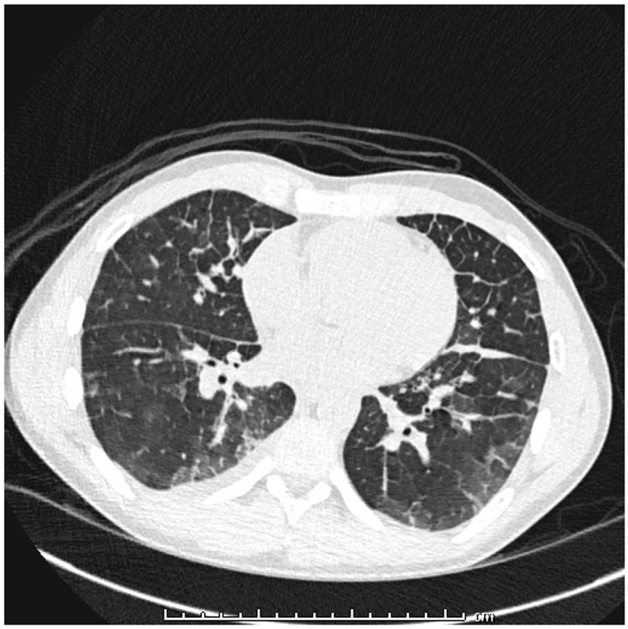

FIGURE 2 Case 3, chest CT: scattered patchy ground-glass opacities, predominantly in subpleural location; smooth interlobular interstitial thickening. CT, computed tomography

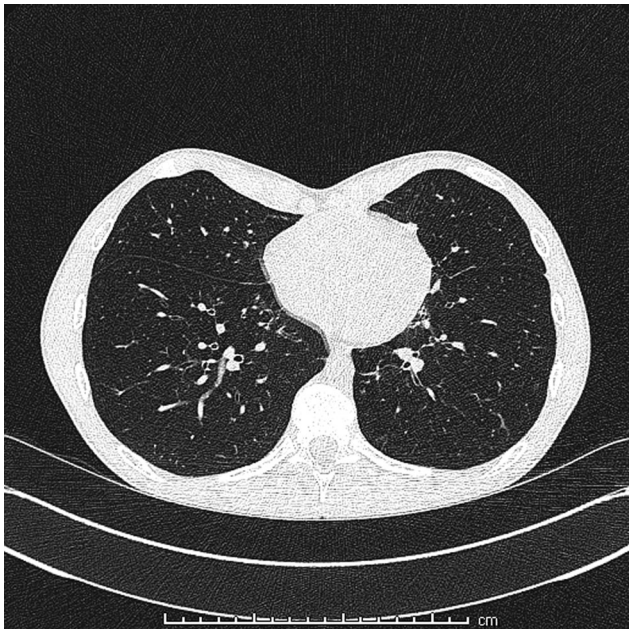

FIGURE 4 Case 5, chest CT: tree-in-bud opacities in the left lower lobe, air-trapping, and subsegmental bronchiectasis in upper segment of left lower lobe (site of previous pneumonia). CT, computed tomography

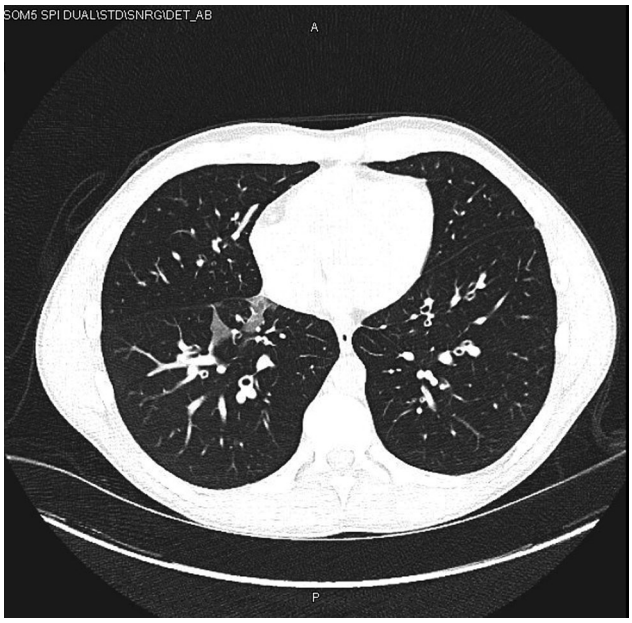

FIGURE 5 Case 7, chest CT: scattered patchy/nodular areas of ground-glass and tree-in-bud opacities in the bilateral lower lobes. Moderate diffuse bronchial wall thickening. CT, computed tomography

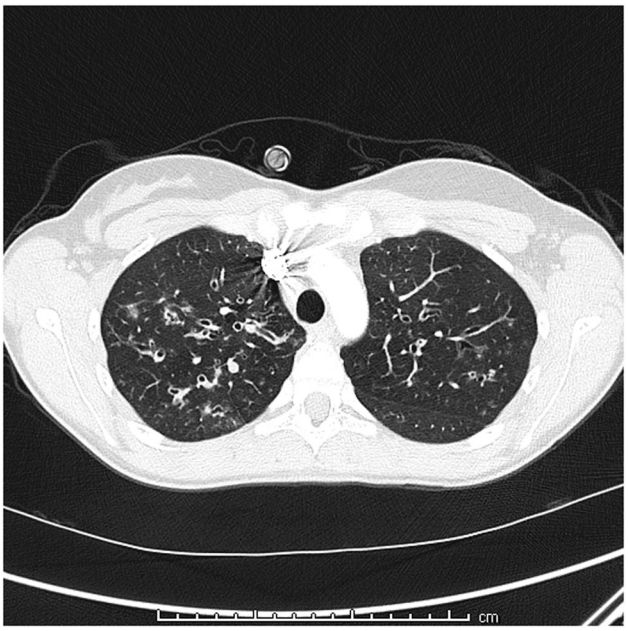

FIGURE 7 Case 9, chest CT: apical predominant bronchiectasis with bronchial wall thickening; tree-in-bud nodularity with pulmonary nodules, some with cavitation. CT, computed tomography

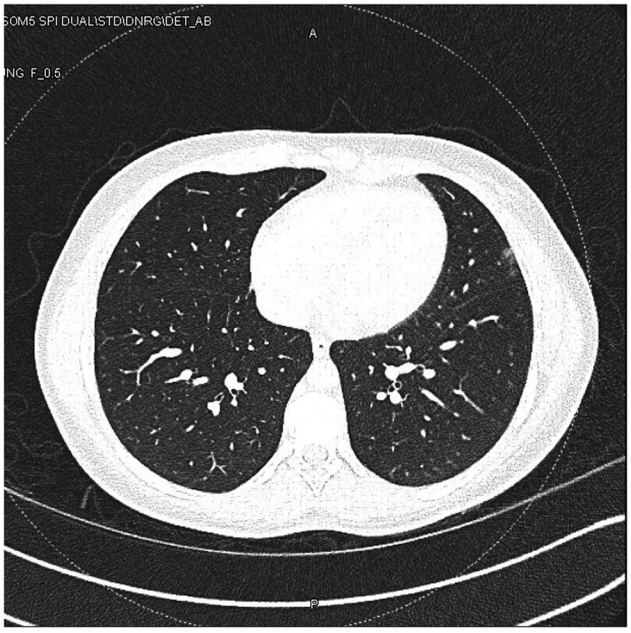

FIGURE 6 Case 8, chest CT: nodular tree-in-bud and ground-glass opacities, mostly in the lingula. CT, computed tomography

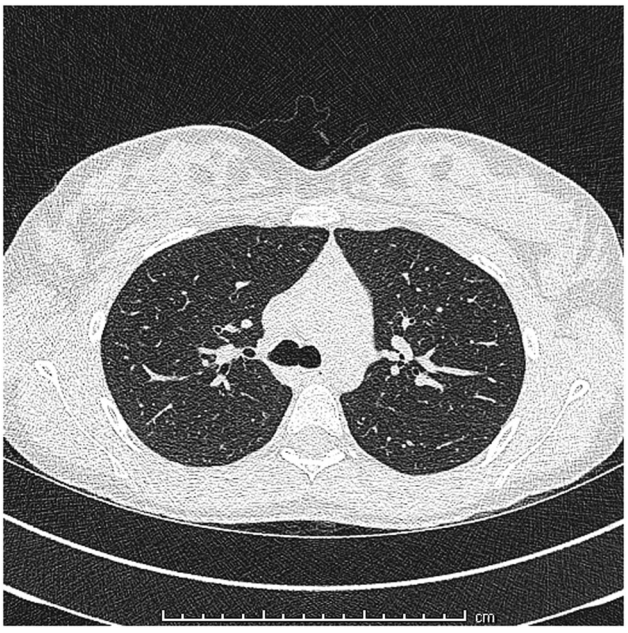

FIGURE 8 Case 10, chest CT: normal chest CT. CT, computed tomography

Notably, this case series is limited to acute presentations of vaping-related respiratory illness. Furthermore, several patients reported inhaling additional substances; the interplay between e-cigarette use and additional inhaled substances is not yet described. We encourage legislation to limit product availability, regulation to ensure the safety of the chemical composition of vaping liquids, and the funding of research to determine the toxic effects of acute and chronic use of e-cigarette products.

CONFLICT OF INTERESTS

The authors declare that there no conflict of interests.

AUTHOR CONTRIBUTIONS

Drs APK, DLO, and LEC conceptualized and designed the study, drafted the initial manuscript and critically reviewed the manuscript for important intellectual content. Drs EWB and AMHC conceptualized and designed the study and critically reviewed the manuscript for important intellectual content. All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

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