The Dynamic Airway: Computed Tomography of Airways Diseases

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Clinical Associate Professor
Thoracic Radiology and Nuclear Medicine
Stanford University Hospital, SimInhale 2019
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Thoracic Radiology: analyzing patterns of disease
Another Patient Has Died From Lung Disease After Vaping

Health authorities in Oregon are investigating the case but would not identify the age of the patient or the brand of the device used.

Cases of Vaping-Related Lung Illness Surge, Health Officials Say

Indiana announced a third death linked to the illness on Friday, Minnesota a fourth and California a fifth. State and federal health officials are working urgently to understand the causes.

The Centers for Disease Control and Prevention said there have been more than 200 cases in 25 states of severe lung disease with possible links to vaping.

Steve Helber/Associated Press
Inhalational disease: vaping associated lung disease

Imaging patterns
- Diffuse alveolar damage
- Acute eosinophilic pneumonia
- Nonspecific interstitial pneumonia
- Organizing pneumonia
- Lipoid pneumonia

Mechanism of lung injury:
- Inhaled compounds containing lipids: Nicotine, THC, glycerin, vitamin E,…
- Adulterants in “street” vaping formulations
- Induced lung inflammation
  - macrophage activation
  - Inflammatory cytokines
Global disease burden from inhaled particles

- 4.2 million deaths every year as a result of exposure to ambient (outdoor) air pollution
- 3.8 million deaths every year as a result of household exposure to smoke from dirty cookstoves and fuels
- 91% of the world’s population lives in places where air quality exceeds WHO guideline limits

Mortality from ambient air pollution – maps
Mortality from household air pollution – maps
Interactive global ambient air pollution map

Ambient air pollution
Household air pollution
Campaigns
Black Lung Disease Back and Worse Than Before, Inside Appalachia

By JESSICA LILLY, ROXY TODD & ERIC DOUGLAS • AUG 23, 2019

Robert Bailey holds up before and after photographs of the procedure he underwent to repair his coal dust-damaged lungs.

JESSICA LILLY / WEST VIRGINIA PUBLIC BROADCASTING
Figure 1 Smoking prevalence of lung cancer patients by gender in East Asia, Europe and USA.
Patient with multiple early stage lung cancers
Aims:

- Routine and cutting edge medical imaging modalities for airways and lung diseases
- Medical perspectives on common and uncommon airways diseases
- How thoracic radiology can help address questions in treatment of airways diseases
Computed Tomography scanner
Computed Tomography scanner
CT SCANNER

http://www.youtube.com/watch?v=2CWpZKuy-NE
CT of the chest

- CT is a fantastic modality to image lungs
  - Fast: Acquisition time 1-2 seconds
  - High inherent contrast, ~1mm resolution
    - Air -1000 Hounsfield Unit (HU)
    - Lung -900 HU, soft tissue 20-40 HU
    - Large airways are easily visualized
    - Small airways (terminal bronchioles) are below CT resolution
  - Multiphasic imaging
  - Continued radiation dose reduction
Further lowering of radiation dose will enable broader use of thorax CT

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<th>Year</th>
<th>Description</th>
<th>Dose (mSv)</th>
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<td>Pediatric imaging</td>
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CT scanning creates robust anatomic datasets

Mirza AA…Guo HH. J Cystic Fibrosis. 2019
3-D Printed lung model from cystic fibrosis patient

Mirza AA…Guo HH. J Cystic Fibrosis. 2019
3-D printing from CT for bronchoscopy planning
Tracheobronchial tree: anatomy

- Nasal cavity
- Pharynx
- Larynx
- Trachea
- Primary bronchus
- Diaphragm
- Pulmonary venule
- Pulmonary arteriole
- Alveolar duct
- Alveolus
- Alveolar sac
- Tracheal cartilage
- Lymph node
- Glands
- Connective tissue sheath
- Epithelium
- Nerve
- Small artery
- Trachealis muscle
- Esophagus

Bedayat et al. CPDR 2019
Chung et al. AJR. 2011
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<tr>
<th>Generation</th>
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The lung, alveoli, and the secondary lobule

Nasal cavity
Pharynx
Larynx
Trachea
Primary bronchus
Secondary bronchus
Tertiary bronchus
Respiratory bronchiole
Diaphragm
Pulmonary veins
Bronchiole
Visceral pleura
Interlobular septum
Pulmonary artery
Lymphatics

Kazerooni E A AJR 2001;177:501-519
Pulmonary Function Test (PFT)

- Inspiratory reserve volume: 3100 mL
- Tidal volume: 500 mL
- Expiratory reserve volume: 1200 mL
- Residual volume: 1200 mL
“Take a deep breath in, and hold it”
“Take a deep breath in, and then exhale the air out of your lungs over 5 seconds”
60 year old man with long standing asthma diagnosis, with worsening dyspnea and barking cough

Inspiration

Dynamic forced expiration
3D reconstruction
Tracheobronchomomalacia
Excessive Dynamic Airways Collapse

- Airways collapse with expiration, producing airflow limitation
- High prevalence, in 4-23% of adults undergoing bronchoscopy and as much as 23% of patients with COPD. Believed to be under-diagnosed [1]
- Symptoms of cough, dyspnea, wheeze, sputum production, recurrent infections
- Commonly masquerade as “treatment refractory” asthma or COPD
- Worse outcome when associated with COPD [2]

Lung volume analysis

**Inspiratory Phase**
- Excluded Airway
- Left Lung: 2192 cm³
- Right Lung: 2781 cm³
- Low Att (Left Lung): 4.24 cm³ (0.193%)
- Low Att (Right Lung): 3.10 cm³ (0.111%)
- Left Lung + Right Lung: 4973 cm³
- Low Att: 7.33 cm³ (0.147%)
- Threshold: -550 HU, Anti-noise: 1

**Expiratory Phase**
- Excluded Airway
- Left Lung: 1440 cm³
- Right Lung: 1653 cm³
- Low Att (Left Lung): 0.160 cm³ (0.0119%)
- Low Att (Right Lung): 0.408 cm³ (0.0245%)
- Left Lung + Right Lung: 3093 cm³
- Low Att: 0.567 cm³ (0.0189%)
- Threshold: -550 HU, Anti-noise: 1
3D post-processing measurements of trachea
Airways measurements: TBM

336 mm²

29 mm²

% narrowing = 100 x [1 – (29 / 336)]

% narrowing = 91.4 %
Airways measurements: Normal

\[ \text{% narrowing} = 100 \times \left[1 - \left(\frac{114}{220}\right)\right] \]

\[ \text{% narrowing} = 48.2 \% \]
Bronchoscopy
TBM: Treatment

- Positive airway pressure support
- Stenting
- Tracheoplasty
- Research:
  - tracheal transplant
  - 3D printed and tissue engineered trachea

Freitag and Dumon Y - Stents

Arthur Sung MD, Stanford Healthcare
TBM after Y stent placement
Causes of Excessive Airways Collapse

- COPD
  - Seen in as much as 23% of COPD patients
- Chronic infection
- Idiopathic
- Extrinsic compression
  - Goiter, cardiomegaly, tumor, vascular, post-lung transplant
- Trauma
  - Post-intubation
- Congenital
  - Vascular rings, foregut duplication cysts
- Relapsing polychondritis
- Tracheobronchopathia Osteochondroplastica (TPO)
- Granulomatosis with Polyangiitis (Wegener’s)
- Mounier-Kuhn
Forms of Airways Collapse:

- Saber sheath
- Lunate
- Circumferential
- Bronchomalacia
Cases: extrinsic compression by goiter
Case: Dyspnea with pneumomediastinum

Relapsing Polychondritis, with posterior tracheal rupture
Cases: young woman with cANCA+

Granulomatosis with PolyAngiitis (Wegener’s)
Cases: Immigrant from central America

Klebsiella rhinoscleroma
Cases: Young man with pectus deformity and recurrent lung abscesses
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3-D Printed model of the thoracic inlet
Cases: Young woman with shortness of breath, PFT: restrictive lung disease
Diagnosis: Pickwickian syndrome

Expiratory Phase

- Excluded
- Left Organ: 470 cm³
- Right Organ: 766 cm³
- LowAtt (Left Organ): 0.0212 cm³ (0.00451%)
- LowAtt (Right Organ): 0.0469 cm³ (0.00613%)
- Left Organ + Right Organ: 1236 cm³
- LowAtt: 0.0681 cm³ (0.00551%)
- Threshold: -960 HU Anti-noise: 1

Inspiratory lung volume: 1.6 Liters
Expiratory lung volume: 1.2 Liters
Bronchial and bronchiolar disease

Expiratory phase demonstrating air trapping, distal airways collapse
The lung, alveoli, and the secondary lobule

Kazerooni E A AJR 2001;177:501-519
Inspiratory and end expiratory phase CT
“Take a deep breath in, and then blow all of the air out of your lungs, and hold it”
Small airways disease: asthma
Patient after bone marrow transplant, with suspected bronchiolitis obliterans
Lung density based quantification of air trapping
CT density based emphysema quantification
Summary: Quantitative and Dynamic Airways CT

- CT scanning in different respiratory phases improves diagnosis of lung and airways disease
- Air-trapping is an indirect indicator of bronchiolar (small) airways disease
- CT imaging complements traditional flow based pulmonary function testing
Other Imaging Modalities: conventional radiograph

Posterior – Anterior radiograph
Other Imaging Modalities: Positron Emission Tomography

F^{18}\text{-FDG} PET-CT tracer and imaging acquisition
Other Imaging Modalities: Positron Emission Tomography

$\gamma$ (511 keV) \quad \beta^+ + e^- \quad \gamma$ (511 keV)

$\beta^+$

$^{18}$F-FDG

F$^{18}$-FDG PET-CT of metastatic lung cancer
Other Imaging Modalities: nuclear medicine V

$^{133}$Xe ventilation scan with washout
Other Imaging Modalities: nuclear medicine V/Q

$^{99}$Tc MAA perfusion and $^{99}$Tc DTPA ventilation scan for pulmonary embolism
Other Imaging Modalities: hyperpolarized gas MRI

Roos et al, MRICNA, 2016
Other Imaging Modalities: hyperpolarized gas MRI

Dissolved hyperpolarized $^{129}\text{Xe}$ in healthy and patient with pulmonary fibrosis

Roos et al, MRICNA, 2016
Summary:

- Modern imaging captures high anatomical detail
  - Potentially available images from large, heterogenous populations
- Continued advancement into low-dose or no-dose, quantitative, functional imaging
- Screening, diagnosis, treatment response, and improve understanding of disease processes and prevention
- Help develop future treatments
References:

10. West JB. Comparative physiology of the pulmonary circulation. Compr Physiol. 2011;
Thank you!

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