New Horizons in the Imaging of the Lung

Postprocessing.
How to do it and when do we need it?

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Post-processing
Standard techniques

- Multi Planar Reformation (MPR)
- Maximum Intensity Projection (MIP)
- Minimum Intensity Projection (minIP)
- Radial Imaging / Paddlewheel reconstruction
- Volume Rendering (VR)
Post-processing
Advanced Visualization techniques

• Fly-through / Virtual Bronchoscopy
• Volume Measurement
• Multi-modality viewing

• Computer Aided Detection (CADe)
  – Pulmonary Embolism
  – Emphysema
  – Lung Nodules
Limitations associated with axial images:

- Limited ability to detect subtle airway stenoses
- Underestimation of craniocaudal extent of disease
- Difficulty displaying complex 3D relationships of the airways
- Inadequate representation of the airways that are oriented obliquely to the axial plane

Boiselle et al. AJR 2002
Axial CT at level of aorticopulmonary window:
large nodal mass (N) compressing carina.
Origin of right mainstem bronchus (arrow)
severely narrowed but difficult to fully assess

Coronal MPR: relationship of
large nodal mass (N) to airway

Boiselle et al. AJR 2002
Post-processing
Multi Planar Reformation (MPR)
Post-processing
Multi Planar Reformation (MPR)

- Multiplanar reformatting is used to assess the extent of disease processes in the craniocaudal direction.
- MPR also useful in assessment of endobronchial stent placement.
- MIP:
  - Examination of pulmonary vessels
  - Detection and examination of nodules
- MinIP:
  - Evaluation of the airways
  - Detection and evaluation of emphysema
Post-processing
Paddlewheel reconstruction

Coronal reconstruction: pulmonary embolus covered in 4 slice volume

Transversal reconstruction: pulmonary embolus covered in 12 slice volume

Courtesy: Chiang et al, Radiology 2003
Post-processing
Paddlewheel reconstruction

Paddlewheel reconstruction: pulmonary embolus covered in a single slice volume

Courtesy: Chiang et al, Radiology 2003
Post-processing
Paddlewheel reconstruction + MinIP

Rotational “paddle-wheel” reformation of normal central airways in 57yo male.

MinIP used to enhance visibility of airways in lung parenchyma. Evidence of emphysema.

Boiselle et al. AJR 2002
Post-processing
3D Volume Rendering

• VR is especially helpful because the degree of transparency can be controlled and, when slab clip plane editing is used, can display the airways in great detail.

• Color assignments can be used to highlight stents.

• VR of the lungs can be performed with varying degrees of transparency to highlight differences in lung aeration.

• A series of preset views can be used to expedite the review process.

Horton et al. AJR 2007
A threshold value of -400 to -600 HU is optimal for visualization of the central bronchial tree.

A threshold of -750 HU is better for evaluation of the distal airway branches.
• 3D CT of the lungs and airway can be used to display the normal anatomic features of the tracheobronchial tree and to identify normal variants.
• 3D CT can depict the airway down to the sixth- and seventh-order subdivisions.
• This 3D map can be used to guide bronchoscopy or to direct transbronchial needle biopsy.
Axial CT shows large nodal mass (N) compressing carina. Origin of right mainstem bronchus (arrow) is severely narrowed but is difficult to fully assess.

3D image shows severe narrowing of proximal right mainstem bronchus (arrow) with distal patency.

*Boiselle et al. AJR 2002*
Anomalous origin of right upper lobe segmental bronchi from right mainstem bronchus in 7yo girl with recurrent respiratory infections.

Apical (1), anterior (2), and posterior bronchus (3) originate directly from right mainstem bronchus rather than from traditional right upper lobe bronchus. Severe bronchiectasis (arrows) in anterior segment can also be seen as well as mosaic pattern of lung attenuation.

Boiselle et al. AJR 2002
Post-processing
3D Volume Rendering

Extensive acute central PE with “saddle embolus” extending into both central pulmonary arteries in a 72yo male.

VR allow intuitive visualization of the location and extent of embolus (arrows).

Schoepf et al. Radiology 2004
Post-processing
3D Volume Rendering

Possible clinical applications:
• Anatomical evaluation
• Pulmonary embolism
• Bronchus narrowing
• Pulmonary masses
Virtual bronchoscopy produces high-resolution images of the tracheobronchial tree and endobronchial views that simulate the findings at conventional bronchoscopy.

Interest in virtual bronchoscopy is increasing as a result of improvements in computer hardware and software and advances in MDCT that allow acquisition of isotropic data.
Advantages of virtual over using conventional bronchoscopy are:

- Decreased burden on the patient
- Ability to move beyond the site of the first obstruction
- Visualize the smaller airways not accessible with fiberoptic bronchoscopy

Horton et al. AJR 2007
Post-processing
Fly-through / Virtual Bronchoscopy

Reported use to:

• Identification of anatomic variants (e.g. tracheal and bronchial diverticula)
• Foreign body aspiration
• Detect and grade benign and malignant airway stenosis
• Transeoesophageal Fistula
• Inhalation burn injuries
• Guidance of transbronchial needle aspiration of mediastinal and hilar nodes and masses
• Stent planning and follow-up
• Follow-up after radiotherapy or laser treatment in pts. with malignant lesions

Horton et al. AJR 2007
Boiselle et al. Chest 2002
Naidich et al. J Thoracic Imaging 1997
Post-processing
Fly-through / Virtual Bronchoscopy

• Virtual Bronchoscopy has a higher specificity, sensitivity and accuracy than axial CT-imaging for the study of the bronchial tree especially in the evaluation of the airway diameter and the morphology of the carina

• Both techniques however have a low sensitivity for the evaluation of the tracheal and bronchial wall

De Wever et al.
Limitations:

- Static examination
- Natural color is absent
- Spatial resolution is limited
- Concurrent interventions are not possible
- Radiation exposure is involved
Advantages

• Non-invasive
• Stenosis, obstructions or endoscopically inaccessible areas are no obstacle for virtual endoscopy
• Extraluminal information is always available and provides guidance for ensuing interventions
• Through distortion-free presentation modes (MPR, mIP, etc) exact measurement can be achieved
Post-processing
Volume measurement

- Volume measurement assists in evaluating the response to tumor therapy
- Fast and robust automatic segmentation and volumetry method for solid lung nodules are developed
- Partly-solid and non solid nodules require more user interaction
Marker registration allows automatic comparison of nodule volumes, calculation of doubling times, and report generation.
Post-processing
Focal parenchymal opacification

Results are reproducible in cases of large, irregular nodules that are connected to other structures.
Simulation results: volume estimation precision by nodule diameter and CT scan slice thickness. Larger precision estimates are associated with greater variability in volume estimation.
Inconsistency is often seen in manual assessment; in contrast, evaluation using volumetric software has good reproducibility, even when the relative change in tumour volume is small.

Because of this confidence in estimating VDT highly depends on the degree of observed growth and on the CT scan slice thickness.

The performance of CT scanners with slice thicknesses of > 2.5 mm for assessing growth in pulmonary nodules is essentially inadequate for 1 mm changes in nodule diameter.

Honda et al., Br J of Radiol 2009
Nietert et al., Chest 2009
• interscan variability of semiautomated volume measurements for pulmonary persistent pure ground-glass nodules

• Nodule segmentation was successful in 98.3% (177/180) and 97.8% (176/180) of measurements with sharp and medium sharp reconstruction kernel, respectively

• Variations in volume measurements of persistent pure ground-glass nodules using commercial software were reasonably small, allowing the detection of clinically relevant growth.
45-yr-old male with persistent pure ground-glass nodules.
8 mm pure ground-glass nodule in the right lower lobe (arrow). Using LungCare software, pure ground-glass nodule was detected by observer using transverse thin-slab MIP and manually marked. Volume of this nodule is 305.96 mm³.
CT virtual bronchoscopy: normal tracheal sidewall and carina without indication of large tumors that abut central airways.

PET/CT virtual bronchoscopy: Highly 18F-FDG–avid malignant subcarinal / paratracheal mass that extends along right tracheal sidewall and right bronchus.

Quon et al. J of Nucl Med 2006
3D-rendered PET/CT aiding spatial localization of metastatic lymph nodes.

Quon et al. J of Nucl Med 2006
Post-processing CADe

• In most instances, CADe plays a complementary role in clinical practice, serving as a second opinion
• Goal is to help radiologists make a more accurate, reliable and rapid diagnosis from large image sets
• Automatically identify and mark abnormalities for further review by radiologist
Post-processing CADe

- Decision support tool
- Will *not* replace radiologists (at least not for now)
- May *augment* radiologist performance / accuracy
- May *augment* radiologist efficiency
Computer Aided Detection (CADe)  
Pulmonary Embolism

Readers’ sensitivity, with and without CAD, per PE

<table>
<thead>
<tr>
<th></th>
<th>Reader 1 sensitivity</th>
<th>Reader 2 sensitivity</th>
<th>CAD sensitivity</th>
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<tbody>
<tr>
<td>Reader Alone</td>
<td>35.29%</td>
<td>64.71%</td>
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<tr>
<td>Reader+CAD</td>
<td>68.07%</td>
<td>73.11%</td>
<td>78.15%</td>
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</table>

Blackmon et al. Eur Radiol 2011
Computer Aided Detection (CADe) Pulmonary Embolism

Readers’ sensitivity and specificity, with and without CAD, per patient

<table>
<thead>
<tr>
<th>Reader 1 sensitivity</th>
<th>Reader 2 sensitivity</th>
<th>Reader 1 specificity</th>
<th>Reader 2 specificity</th>
<th>CAD sens.</th>
<th>CAD specif.</th>
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</thead>
<tbody>
<tr>
<td>Reader Alone</td>
<td>78.13%</td>
<td>90.63%</td>
<td>93.62%</td>
<td>91.49%</td>
<td>93.75%</td>
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<tr>
<td>Reader+CAD</td>
<td>90.63%</td>
<td>93.75%</td>
<td>89.36%</td>
<td>87.23%</td>
<td>14.89%</td>
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</table>
• Expert consensus revealed 119 PEs in 32 studies.

• For PE detection, the sensitivity of CAD alone was 78%.

• Inexperienced readers’ initial interpretations had an average per-PE sensitivity of 50%, which improved to 71% (p<0.001) with CAD as a second reader.

• False positives increased from 0.18 to 0.25 per study (p=0.03).
• Per-study, the readers initially detected 27/32 positive studies (84%); with CAD this number increased to 29.5 studies (92%; p=0.125).

• CAD significantly improves the sensitivity of PE detection for inexperienced readers with a small but appreciable increase in the rate of false positives.

Blackmon et al. Eur Radiol 2011
Computer Aided Detection (CADe) Emphysema

- Visual assessment of low attenuation lung disease on MDCT is based on the detection of:
  - Lung destruction
  - Areas of abnormal lung attenuation
  - Abnormal caliber and distribution of blood vessels

- In early disease these signs can be very subtle and especially the interpretation of abnormal lung attenuation can be difficult
Computer Aided Detection (CADe) Emphysema

- Visualization using density masks gives objective geographical information solely based on pixel density and can highlight focal and diffuse density changes.
- The density masks are constructed by assigning different colors to highlight different density ranges.
- Lung pixels with HU values between -200 and -1000 are assigned with a different color for each range of 100 HU thus creating colored density mask images.
Computer Aided Detection (CADe)
Lung nodules

<table>
<thead>
<tr>
<th>Resident</th>
<th>Year of Residency</th>
<th>No. Nodules Found Without CAD</th>
<th>No. Nodules Found With CAD</th>
<th>Sensitivity Without CAD, %</th>
<th>Sensitivity With CAD, %</th>
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<tbody>
<tr>
<td>1</td>
<td>Second</td>
<td>81</td>
<td>84</td>
<td>89</td>
<td>92.3</td>
</tr>
<tr>
<td>2</td>
<td>Second</td>
<td>76</td>
<td>79</td>
<td>83.5</td>
<td>86.8</td>
</tr>
<tr>
<td>1</td>
<td>Third</td>
<td>84</td>
<td>85</td>
<td>92</td>
<td>93</td>
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<tr>
<td>2</td>
<td>Third</td>
<td>73</td>
<td>76</td>
<td>80.2</td>
<td>83.5</td>
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<tr>
<td>1</td>
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<td>77</td>
<td>85</td>
<td>84.6</td>
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<tr>
<td>2</td>
<td>Fourth</td>
<td>73</td>
<td>82</td>
<td>80.2</td>
<td>90.1</td>
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</tbody>
</table>

Number of Nodules Identified by the Residents in the Different Years in the Residency Program and the Sensitivity of the Residents Without and With CAD Application.
• CADe can be an effective second reader and help improve the sensitivity of radiology residents in the detection of pulmonary nodules on CT

• CADe improved sensitivity of residents in detecting lung nodules to a level comparable with board-certified radiologists
How do we do it? When do we need it?

- Start from the axial slices and use additional visualizations based on the clinical question at hand
- Use CADe as a second reader when available
- Amount of data is growing hampering axial evaluation, therefore in almost every case additional post-processing is required varying from simple MPR to advanced CADe depending on the situation
New Horizons in the Imaging of the Lung
Postprocessing. How to do it and when do we need it?

Thank you for your attention