Post treatment contribution in semiological analysis of thoracic helical CT

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Learning objectives

- To know the basis of different techniques of reformation used to analyze thoracic CT.
- To illustrate the post treatment contribution in semiological analysis of different tracheo-bronchial, pleural, parenchymal and parietal chest abnormalities.
- To describe the conditions requiring the use of Maximum intensity projection (MIP) and minimum intensity projection (mIP) and volume rendering reformations.
Background

- The progressive improvements in CT technology challenge our daily practice by introducing multiplanar reformations (MPRs) and three-dimensional (3D) images.
- Whereas every radiologist is skilled in forming mental multiplanar and 3D reformations from cross-sectional images, there are multiple situations in which additional reformats may help improve the overall diagnostic impact of a spiral CT examination.
- For the radiological community, MPRs and/or 3D images offer the ability to complement cross-sectional images whenever the latter are not perfectly suited to evaluate complex anatomical situations.
- However, one should not overlook the importance of MPRs and 3D images as communicating tools, enabling the radiologist to provide the referring clinicians with synthetic information whenever necessary but also university centers to update anatomy teaching.
- Due to the recent introduction of postprocessing technologies in medical practice, multiplanar and 3D images are still in an evaluation phase but their rapid development should be underlined.
- Consequently, the purpose of this review consists in capturing the current state of the art of these new image processing modalities.
Imaging findings OR Procedure details

- Between January 2008 and August 2009, 100 patients with thoracic pathology were included in our study.
- All examinations were performed in Medical Imaging department, CHU Sahloul in Sousse Tunisia on a 16 multi slice scan programmed for multiplanar reformations and three-dimensional techniques using intensity projection and volume rendering techniques.

Image acquisition and reconstruction

- Because the lung parenchyma has a unique natural contrast, a low radiation dose (80-100 kV, 60-80 mAs) is used for multi- detector row CT.
- Images are acquired with a 16 detector row CT scanner during a single breath hold lasting about 4-10 seconds, making respiratory motion artifacts very unusual.
- A high-frequency algorithm, a 512 x 512 matrix, and a 325 mm field of view are used, with a rotation time of approximately 500 msec that allows a marked decrease in cardiac pulsation artifacts.
- With a detector size of 0.625 or 1.25 mm, we produce a voxel of almost cubic dimensions allowing the creation of excellent 2D and 3D reformatted images.

Postprocessing techniques

- Prior to the description of the current and expected clinical applications of MPRs and 3D images, a brief summary of the technical peculiarities of the postprocessing techniques currently available is presented.

A- TWO-DIMENSIONAL MULTIPLANAR RECONSTRUCTION (MPR)

- The volume data acquired with MDCT can be displayed in various planes selected two-dimensionally.
- These two-dimensional reformatted images are generally performed in the coronal and sagittal planes.
- Combination use of three planes, axial, coronal and sagittal, MPR images is essential to interpret a CT study with MDCT (fig 1).
- Reformations in oblique and curved planes can also be made, which allow a structure to be traced and displayed as if it lay along a single axis.

B- MAXIMUM AND MINIMUM INTENSITY PROJECTION (MIP AND MINIP)

- Maximum intensity projection (MIP) and minimum intensity projection (mIP) are created in a similar fashion.
Those are 3D rendering techniques that evaluates each voxel along a line from the viewer's eye through the volume of the data and selects the maximum voxel value for MIP and the minimum voxel value for mIP.

MIP and mIP images have a tendency to misrepresent spatial relationships and limited use in areas overlapping structures.

This limitation can be partially overcome with use of sliding slab MIP reconstructions.

Variable thin slabs can be scrolled interactively through the volume and displayed on a monitor to define anatomic relationship.

The application of MIP reconstructions for the lung has been shown initially to increase nodule detection and can help differentiate between small nodules and vessels.

The lumina of airways and emphysematous changes are shown to better advantage with mIP images, which highlights low attenuation structures, such as the airways and air cysts than with conventional CT images.

C- THREE DIMENSIONAL VOLUME RENDERING

- Volume rendering is generally preferred over surface rendering because of the inherent advantage of displaying the entire range of voxel attenuation values.
- By choosing different parameters, the data can be segmented by attenuation value to display the desired structure.
- Volume rendering can be performed from external and internal perspectives allowing the user to «fly around» and «fly through» the structures.
- The endoluminal «fly through», also referred to as virtual endoscopy, allow the user to navigate through hollow structure in a fashion similar to that of conventional endoscopy.
- Applications of these «fly through» and «fly around» techniques include evaluating airway stenoses, guiding transbronchial biopsies, screening for endobronchial neoplasms, and guiding video assisted thoracic surgeries (VATS) for lungs.
- Three dimensional volume rendering can provide a map of relevant anatomy for the surgeon.
- In VATS the surgical field of view with endoscopic instruments is limited to indirect visualization of a small region, so that preoperative simulation maps with 3D volume rendering play important roles.

Imaging findings

A- Diffuse Lung Disease

- Diffuse lung disease may have an acute or a chronic cause.
- Acute causes include pulmonary edema, diffuse alveolar damage (adult respiratory distress syndrome), diffuse pulmonary hemorrhage,
hypersensitivity pneumonitis, acute interstitial pneumonia, and acute infectious bronchiolitis.

- Chronic causes include chronic infiltrative lung disease, emphysema, chronic obstructive pulmonary disease, and obliterative bronchiolitis.
- Multi-detector row CT facilitates the detection of the various patterns of diffuse lung disease.
- With this modality, it is easier to recognize the predominant pattern of distribution, which is important for developing the differential diagnosis.
- Abnormalities are also more easily identified in relation to the underlying vascular, bronchial, and lobular anatomy.
- Actually, the assessment of the perilobular, centrilobular, or panlobular distribution of findings is crucial to making a correct diagnosis.

a- Linear Pattern

- A linear pattern may correspond to
  - thickening of the interstitial fiber network of the lung owing to fluid,
  - fibrous tissue
  - interstitial infiltration by cells or other material.
- Longitudinal reformation provides additional information of great value in this setting.
- These patterns are best imaged with MIP, whatever their cause.
- Abnormal septal lines, which are easily assessed with this technique, may be related to a variety of disorders such as rejection, pulmonary edema, fibrosis, or lymphangitis carcinomatosis.
- In cases of perilymphatic distribution, consisting of peribronchovascular thickening and abnormal nodular septal lines, MIP is the reformatting technique of choice for evaluating the size of pulmonary vessels and to assess distribution of nodules.
- Reticular patterns, which usually reflect intralobular interstitial thickening, are most commonly seen in patients with pulmonary fibrosis (fig 2).
- The great advantage of mIP in this setting is its capacity to help correctly evaluate the distribution of reticular opacities, while at the same time helping assess for possible traction bronchiolectasis or discrete "honeycombing," both of which entities are difficult to appreciate on axial images alone (fig 3).

b- Nodular Pattern

- A nodular pattern is often difficult to evaluate solely on the basis of its attenuation and definition.
- More useful is the assessment of its regional distribution, both in the craniocaudal and axial dimensions and within the secondary pulmonary lobule.
- MIP with progressively increasing slab thickness is very helpful because it improves the detection of small nodules and the estimation of their profusion, thereby helping in the recognition of their characteristic
distribution relative to the landmarks of the secondary pulmonary lobule (fig 4, 5).

c- Ground-Glass Pattern

- The ground-glass pattern is defined as an abnormal increased attenuation of the lung parenchyma without erasing of vessels or bronchi shapes. It may correspond to partial or, rarely, total alveolar filling, thickening of alveolar septa with partial collapse of alveoli (with or without lung fibrosis), or an increase in blood capillary size.
- Ground-glass attenuation can be focal or diffuse and homogeneous or heterogeneous and can develop in an acute or chronic context.
- It is sometimes difficult to assess on axial images alone but may be more easily demonstrated with mIP as an abnormal contrast between endobronchial air and hyperattenuating lung parenchyma (fig 6, 7).
- Moreover, it can be used to guide the endoscopist in selecting the best area in which to perform bronchoalveolar lavage.
- MIP must also be performed in this setting to differentiate ground-glass attenuation with a mosaic pattern from mosaic perfusion.
- In cases of ground-glass attenuation with a mosaic pattern, the vessels will be of equal size throughout the lungs.
- MIP should also be systematically performed in cases of perihilar or dependent ground-glass attenuation.
- In these cases, hydrostatic pulmonary edema may readily be distinguished from other causes of groundglass attenuation on the basis of enlarged pulmonary veins.
- The crazy-paving pattern consists of a combination of ground-glass attenuation and reticular lines in the same area and often reflects chronic filling of the alveoli from various causes.
- This pattern was originally described in pulmonary alveolar proteinosis. However, it may occur in many other diseases, including hypersensitivity pneumonitis, bronchoalveolar cell carcinoma, lipoid pneumonia, *P carinii* pneumonia, chronic eosinophilic pneumonia, pulmonary edema, and pulmonary hemorrhage (fig 8).
- The crazy-paving pattern is a clinical indication for bronchoalveolar lavage, which provides the key to identifying its cause.

d- Decreased Lung Attenuation

- Decreased lung attenuation is a characteristic finding in lung cysts, honeycombing, emphysema, and mosaic perfusion.
- A pattern of multiple cysts distributed throughout the lungs is suggestive of Langerhans cell histiocytosis or lymphangioleiomyomatosis.
- In patients with Langerhans cell histiocytosis, nodules are often associated with cysts, and both involve the upper two-thirds of the lungs, sparing the costophrenic angles (fig 9).
• In patients with lymphangioleiomyomatosis, the lung cysts are thin walled, numerous, of varying size, and often large, involving the lung diffusely without any topographic predominance. The cysts are surrounded by relatively normal lung parenchyma.

• mIP in the optimal oblique plane-in most cases along the long axis of the bronchus-permits differentiation of cystic bronchiectasis from lung cysts.

• mIP is also the best technique for depicting centrilobular emphysema (fig 9).

• However, multiplanar VR averaging is the best postprocessing technique for depicting a central dot, which represents the remaining centrilobular artery, within a round hypoattenuating area, findings that are characteristic of centrilobular emphysema. Such a central dot is not seen in lung cysts.

• The term honeycombing refers to the characteristic appearance of extensive end-stage pulmonary fibrosis, resulting from lung destruction and obliteration of the acinar architecture. At multi-detector row CT, the cystic spaces in honeycombing commonly share walls, are predominantly subpleural, and occur in several layers (fig 10).

• Honeycombing is most commonly caused by idiopathic pulmonary fibrosis, collagen vascular disease, endstage hypersensitivity pneumonitis, or asbestosis. It may have an atypical distribution, particularly in sarcoidosis, drug-related fibrosis, and hypersensitivity pneumonitis. In such cases, a focal area of honeycombing may mimic paraseptal or cicatrizing emphysema.

• Multiplanar VR-mIP is helpful in showing the airway with distal bronchiolectasis converging into a honeycombing pattern. Such findings are not present in cases of emphysema (fig 10 bis).

• MIP helps evaluating the vascular architecture in areas of decreased lung attenuation. This capacity is particularly valuable in differentiating emphysema from constrictive bronchiolitis. The latter is characterized by a poor but preserved vascular architecture. Conversely, a disorganized architecture is demonstrated in most cases of emphysema.

• Sometimes it is impossible to differentiate between the two disease processes; in such cases, texture-based image analysis may be

• Finally, MIP is the tool of choice in facilitating a definite diagnosis of mosaic perfusion. This pattern is characterized by hypoattenuating attempted areas with small vessels that correspond to pathologic change and by hyperattenuating areas with enlarged vessels that correspond to normal lung with redistribution of perfusion. These findings may be related to small airway disease or a primary vascular abnormality, mainly due to chronic thromboembolic pulmonary disease.

B- Solitary Pulmonary Nodule

• The imaging evaluation of solitary pulmonary nodule (SPN) can be a complex process.

• The primary role of radiologic evaluation is to differentiate benign from malignant pulmonary nodules.
• Assessing the growth rate or more precisely the doubling-time of pulmonary nodules is one of the best predictors of malignancy.
• Volumetric growth estimation based on repeated 3D volumetric measurements of small pulmonary nodules is more accurate than estimation of growth rate on axial CT images.
• The 3D analysis of small pulmonary nodules may be one of the key tools for non-invasive assessment of growth rate and morphology of small pulmonary nodules.
• Differentiation of a small nodule from a vessel and its relationship to a bronchus or vessel is also elegantly demonstrated on MDCT.
• Multidetector CT allows for the analysis of the kinetics of contrast enhancement of a nodule facilitating benign versus malignant differentiation.

C- Airways

a- Congenital anomalies

• A variety of congenital anomalies may affect the central airways, including: branching anomalies, congenital stenosis, congenital malacia, congenital, Tracheobronchomegaly and congenital diverticula: single or multiple invaginations of the tracheal wall. They commonly arise 4 to 5 cm below the vocal cords or 2 to 3 cm above the carina on the right lateral aspect of the trachea.
• Diagnosis is usually easy on cross sectional images but some anatomic variants of bronchi are best assessed on coronal MPR and VR reformations such as bronchus trachea, accessory cardiac bronchus …
• Reformations enable extent of tracheal anomalies and detect mild anomalies (fig 11).

b- Central airways

b1) Tracheobronchial stenoses

• Tracheobronchial stenosis is defined as focal or diffuse narrowing of the tracheal lumen. It may occur secondary to a wide variety of benign and malignant causes
• It is sometimes difficult to appreciate slight variations in the transverse shape of airway sections in a redundant series of axial reconstructed slices.
• It may be hard to perceive the reduction of vertical diameter of structures lying in planes that are parallel or slightly oblique to the transverse one, or to precisely measure the craniocaudal extent of a lesion, by review of axial sections.
• Focal strictures like post-intubation webs or anastomotic stenoses and lesions developing in complex planes like some congenital pathology may be difficult to evaluate by transverse sections alone.

• In all these and other similar cases, the simplest and interactive MPR/MPVR reconstructions are usually sufficient to complete diagnostic depiction: localization and measurement of bronchial stenosis (fig 12, 13).

• Their diagnostic accuracy has proved to be equivalent to conventional CT sections; additional benefit is not statistically relevant, and so their use in adjunct to transverse slices might be restricted to selected cases of actual need.

• Additional value regarding diagnostic confidence is much more difficult to evaluate, even though not negligible.

• Airway segments that are difficult to analyze because of post-surgical remodelling can be completely depicted by a single MPR/MPVR section.

• Only in 2D MPR images, and within certain limits in MPVR and after voxel density-based tissue classification in VR, density values are maintained, and it is thus possible to retain the information about tracheobronchial walls and surrounding tissues.

• MinIP projections have no real indications owing to the fact that dominant negative density of central endoluminal voxels may cause small parietal lesions to be overlooked. In adjunct, correct grading of severe stenosis is hard to achieve. However, MinIP projections are often used in frontal plane because the image looks like conventional bronchography.

• VE allows perspective evaluation of central stenosis in a time comparable to that necessary to obtain satisfactory MPR reconstructions, that some VE softwares simultaneously display for real-time correlation.

• Slight parietal alterations, difficult to appreciate by CT images review, are detected with increased confidence by endoscopic perspective.

• Nevertheless, even VE images are affected by motion and beam hardening artifacts, and by the effects of incorrect data acquisition, reconstruction, and segmentation.

• With external Volume Rendering, it is possible to obtain images of the tracheobronchial tree that closely resemble conventional bronchography, that may effectively support transverse section when needed.

b2) Bronchiectasis

• The CT cardinal sign of bronchiectasis is dilatation of the bronchi with or without bronchial wall thickening. The CT criteria for diagnosing cylindrical bronchiectasis include:

  - A bronchial diameter greater than that of the accompanying pulmonary artery.

  - Lack of tapering of the bronchial lumen.

  - Visualization of a bronchial lumen within 1 cm of the costal pleura or a bronchus abutting the mediastinal pleura.
• mIP reformation improve the detection and the assessment of extent of bronchiectasis (fig 14).
• MIP reformations improve detection of infectious complications and distinguish mucoid impactions from bronchiolar nodules
• MIP and mIP reformations facilitate depiction of parenchyma hypoperfusion downstream and the underlying cause: attenuation of the parenchyma (mIP) and constriction of vessel diameter (MIP) reflecting bronchiolitis obliterans (mettre la fig de l’hypoperfusion DDB) (fig 15, fig 16).

b3) chronic obstructive pulmonary disease (COPD)
• Involvement of proximal airways include:
  - Bronchial wall thickening.
  - Saber-sheath trachea: is a deformity defined as excessive coronal narrowing of the intrathoracic trachea with widening of the sagittal tracheal diameter (fig 17).
  - Tracheobronchomalacia refers to weakness of the airway walls or supporting cartilage, and is characterized by excessive expiratory collapse. Dynamic expiratory CT may show complete collapse or collapse of greater than 75% of airway lumen (fig 18).
  - Bronchial protrusions and diverticula: due to hypertrophy and hyperplasia of the bronchial glands. The application of mIP technique on 3-7 mm thick slabs including proximal airways allows the visualization of small air collections in the wall of the main and lobar bronchi (fig 19).

b4) Airway fistula and dehiscence
• Helical CT with thin collimation is the most accurate technique to identify:
  - Oesobronchial fistula secondary to necrotizing pneumonia or post-traumatic.
  - Nodo bronchial and nodobronchioesophageal fistula secondary to Mycobacterium Tuberculosis infection.
  - Cysto-bronchial fistula in case of hydatid cyst complicated by a vomica (fig 20).
  • mIP reformations help depiction of such anomalies by the presence of gas in cavitated hila or mediastinal lymphadenopathy adjacent to the airways. They display directly the fistula tract (fig 21).

b5) Locoregional extent of central tumours
• MPR/MPVR reconstructions are the method of choice for help in local staging of hilar and mediastinal lesions, when needed, because maintaining
voxels density values is essential in order to evaluate neoplastic involvement of surrounding structures.

- It is possible to better depict the relationships between pathological tissue and bronchovascular interfaces, and to precisely evaluate subcarinal and aortopulmonary window lymph nodes (fig 22).
- There is no real indication for the application of more complex rendering techniques in this field.
- VR perspectives are promising, because tissue composition information is retained, and 3D spatial relationships are also displayed. This technique can be useful for better depiction of vascular encasement, but its actual role is still to be defined.

b6) Integration with endoscopic procedures

- CT and bronchoscopy are complementary examinations in diagnostic work-up of tracheobronchial pathology.
- Conventional CT diagnostic accuracy and its use as a road map for bronchoscopy are well-established.
- Helical CT goes one step further owing to continuous volume scanning and speed of acquisition.
- In specific applications, the use of additional rendering techniques may ease information exchange in patient management, increasing CT synergey with fiberoptic bronchoscopy and overcoming some of the limitations of conventional axial scanning. It is obvious then that VB aroused great interest.
- Nevertheless, it is necessary to define its few, selected, actual clinical applications; otherwise, this technique is at risk of being relegated to a corner, after initial enthusiasm, because even medicine and computer technology are subject to marketing rules and 'fashions'.
- 3D reconstructions may show better additional details that may be important in planning endobronchial procedures.
- The correlation of endoscopic findings with VB could facilitate bronchoscopic reperage of pathological features that could be difficult to demonstrate in some patients (fistulas, leakages). Reproducing the course of the endoscope towards a lesion from the trachea to most peripheral bronchi, we can assign a new value to bronchus sign. It could be possible to reduce examination time by preliminary virtual exploration in patients at risk of complications, like in tracheomalacia and in Wegener's granulomatosis, or in children, and to reduce the number of endoscopies performed in the follow-up after endobronchial disobstruction and stenting and after major surgery.
- In most cases, in clinical practice, we must suspend our virtual exploration more or less where the fiberoptic endoscope stops, apart from experimental, targeted examinations, because a minimal lumen diameter of four pixels is required.
• By displaying all possibilities available, it is possible, compensating the pitfalls of one technique with the advantages of the other one, to work together, sharing our efforts, in order to obtain better results.

c- Small airway disease/ bronchiolitis

• Bronchioles become visible in the center of secondary pulmonary lobule when abnormal tissular densities infiltrate the lumen and/or the wall of bronchioles.
• That accounts for the characteristic centrilobular distribution of bronchiolar abnormalities on thin-section scan.

Thin-section CT findings consist of:

• **Direct signs:** centrilobular nodular and branching linear opacities. The association of both nodular and linear branchi opacities gives the "tree-in-bud" appearance reflecting abnormal wall thickening and dilatation of bronchiolar lumen filled with mucous, pus or peribronchiolar inflammation (fig 23). Tree-in-bud sign suggests acute or chronic infectious bronchiolitis. It can be seen in diffuse panbronchiolitis and aspiration bronchiolitis. This sign is often associated to bronchiectasis and bronchial wall thickening.

Low profusion and tiny low attenuating micronodules can be overlooked. MIP reformation is the optimal tool to detect micronodules and assess their distribution and profusion (fig 24).

• **Indirect signs:** Obstruction of the bronchiolar lumen results in hypoxia of the underventilated lungs, reflex vasoconstriction, and air trapping. On CT scans the combination of local vasoconstriction and air trapping results in decreased attenuation of the affected areas of the lung. There is associated blood flow redistribution to areas of normal lung that are therefore of higher attenuation. These changes are usually patchy in distribution and result in adjacent areas of abnormal low attenuation lung and relatively overperfused higher attenuation normal lung. This combination is referred to as mosaic perfusion. The regional differences in lung attenuation and lung perfusion are increased on expiratory scans due to air trapping.
• This pattern can be seen in all constrictive bronchiolitis (fig 25), in hypersensitivity pneumonitis and in asthma.
• Low attenuated lung mosaic perfusion pattern and air trapping are easily diagnosed on MIP projection with various thickness slabs.
• MIP reformations show larger vessels sections in ground-glass attenuation.
Fig. 0: Pyopneumothorax in a 50-year-old man. (a,b) axial, (c) sagittal thin-slice images. Note that sagittal reformation helps to the assessment of the pleural origin of the collection.

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Fig. 0: Fig.1c. Pyopneumothorax in a 50-year-old man. (a,b) axial, (c) sagittal thin-slice images. Note that sagittal reformation helps to the assessment of the pleural origin of the collection.

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Fig. 0: Non specific interstitial pneumonia in a 82 years-old-woman with CREST syndrome. (a) Axial thin-slice, (b) axial mIP (6 mm-thick-slab). Sub-pleural reticular pattern associated to ground-glass opacities and microscopic honeycombing with traction bronchiectasis.

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**Fig. 0:** Recent dyspnea in a 45-years-old male. (a) Axial CT scan of the lung bases shows groundglass attenuation and reticular lines. (b, c,d) Ventral decubitus acquisition: Axial thin-slice, (b), axial MIP reformation (c), axial (d) and sagittal (e) MIP reformation: images clearly depict persistent lesions in a subpleural location with the sagittal image demonstrating their posterobasal location. MIP allows detection of mild traction bronchiectasis and honeycombing. MIP recognizes ground-glass and linear patterns.

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Fig. 0: Fig.3b. Recent dyspnea in a 45-years- old male. (a) Axial CT scan of the lung bases shows groundglass attenuation and reticular lines. (b, c,d ) ventral decubitus acquisition: Axial thin-slice,(b), axial MIP reformation (c), axial (d) and sagittal (e) mIP reformation: images clearly depict persistent lesions in a subpleural location with the sagittal image demonstrating their posterobasal location. mIP allows detection of mild traction bronchiectasis and honeycombing. MIP recognizes ground-glass and linear patterns.

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Fig. 0: Fig.3d. Recent dyspnea in a 45-years-old male. (a) Axial CT scan of the lung bases shows groundglass attenuation and reticular lines. (b, c, d) Ventral decubitus acquisition: Axial thin-slice, (b), axial MIP reformation (c), axial (d) and sagittal (e) MIP reformation: images clearly depict persistent lesions in a subpleural location with the sagittal image demonstrating their posterobasal location. MIP allows detection of mild traction bronchiectasis and honeycombing. MIP recognizes ground-glass and linear patterns.

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Fig. 0: Fig.4a. Sarcoidosis in a 5O-years-old woman: coronal oblique (a) and axial (b) mIP image (3.5 mm thick slab): hilar bilateral fibrosis masses narrowing proximal bronchi. Coronal reformatted image (c) with MIP (d) (3 mm thick slab): demonstrates micronodules distributed along the major fissure more clearly depicted on MIP images.

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Fig. 0: Fig. 4b. Sarcoidosis in a 50-years-old woman: coronal oblique (a) and axial (b) mIP image (3.5 mm thick slab): hilar bilateral fibrosis masses narrowing proximal bronchi. Coronal reformatted image (c) with MIP (d) (3 mm thick slab): demonstrates micronodules distributed along the major fissure more clearly depicted on MIP images.

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**Fig. 0:** Fig.4c. Sarcoidosis in a 50-years-old woman: coronal oblique (a) and axial (b) mIP image (3.5 mm thick slab): hilar bilateral fibrosis masses narrowing proximal bronchi. Coronal reformatted image (c) with MIP (d) (3 mm thick slab): demonstrates micronodules distributed along the major fissure more clearly depicted on MIP images.

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Fig. 0: Fig.5a. Breast cancer in a 75-year-old woman. Axial thin slice (0.625 mm thick slab) (a) and MIP-multiplanar VR images with increasing slab thickness: 6mm thick slab (b) and 8mm thick slab (c): The use of progressively increasing slab thickness improves the detection and assessment of the profusion of metastatic micronodules.

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Fig. 0: Fig.5b. Breast cancer in a 75-year-old woman. Axial thin slice (0.625 mm thick slab) (a) and MIP-multiplanar VR images with increasing slab thickness: 6mm thick slab (b) and 8mm thick slab (c): The use of progressively increasing slab thickness improves the detection and assessment of the profusion of metastatic micronodules.

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Fig. 5c. Breast cancer in a 75-year-old woman. Axial thin slice (0.625 mm thick slab) (a) and MIP-multiplanar VR images with increasing slab thickness: 6mm thick slab (b) and 8mm thick slab (c): The use of progressively increasing slab thickness improves the detection and assessment of the profusion of metastatic micronodules.

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Fig. 0: Fig.6a. Candida pneumonitis in a 43-year-old woman who has underwent kidney graft. Axial (a) and reformatted sagittal (b) CT scans show inhomogeneous lung attenuation. mIP image (3-mm-thick slab) in sagittal (c) and coronal (d) plans show abnormal increased attenuation of the lung parenchyma compared with endobronchial air. This ground-glass attenuation spares the upper portions of the lung; it is secondary to candida pneumonitis in this case. Axial MIP image (e) shows more clearly abnormal thickening of septal lines in postero basal regions.

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**Fig. 0**: Fig.6b. Candida pneumonitis in a 43-year-old woman who has underwent kidney graft. Axial (a) and reformatted sagittal (b) CT scans show inhomogeneous lung attenuation. mIP image (3-mm-thick slab) in sagittal (c) and coronal (d) plans show abnormal increased attenuation of the lung parenchyma compared with endobronchial air. This ground-glass attenuation spares the upper portions of the lung; it is secondary to candida pneumonitis in this case. Axial MIP image (e) shows more clearly abnormal thickening of septal lines in postero basal regions.

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**Fig. 6c:** Candida pneumonitis in a 43-year-old woman who has undergone kidney graft. Axial (a) and reformatted sagittal (b) CT scans show inhomogeneous lung attenuation. mIP image (3-mm-thick slab) in sagittal (c) and coronal (d) plans show abnormal increased attenuation of the lung parenchyma compared with endobronchial air. This ground-glass attenuation spares the upper portions of the lung; it is secondary to candida pneumonitis in this case. Axial MIP image (e) shows more clearly abnormal thickening of septal lines in posterior basal regions.

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Fig. 0: Fig.6d. Candida pneumonitis in a 43-year-old woman who has underwent kidney graft. Axial (a) and reformatted sagittal (b) CT scans show inhomogeneous lung attenuation. mIP image (3-mm-thick slab) in sagittal (c) and coronal (d) plans show abnormal increased attenuation of the lung parenchyma compared with endobronchial air. This ground-glass attenuation spares the upper portions of the lung; it is secondary to candida pneumonitis in this case. Axial MIP image (e) shows more clearly abnormal thickening of septal lines in postero basal regions.

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**Fig. 0:** Fig.6e. Candida pneumonitis in a 43-year-old woman who has underwent kidney graft. Axial (a) and reformatted sagittal (b) CT scans show inhomogeneous lung attenuation. mIP image (3-mm-thick slab) in sagittal (c) and coronal (d) plans show abnormal increased attenuation of the lung parenchyma compared with endobronchial air. This ground-glass attenuation spares the upper portions of the lung; it is secondary to candida pneumonitis in this case. Axial MIP image (e) shows more clearly abnormal thickening of septal lines in postero basal regions.

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Fig. 0: Fig. 7a. Lymphoid interstitial pneumonia in a 72-year-old patient. (a) axial thin-slice, (b) axial MIP image (6.3 mm-thick slab), (c) axial mIP image (5 mm-thick slab). Ground-glass opacity in basal segments of the right lower lobe with a mild reticular pattern and thin-wall cysts. Equal size of vessel in normal and abnormal areas.

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Fig. 0: Fig.7c. Lymphoid interstitial pneumonia in a 72-year-old patient. (a) axial thin-slice, (b) axial MIP image (6.3 mm-thick slab), (c) axial mIP image (5 mm-thick slab). Ground-glass opacity in basal segments of the right lower lobe with a mild reticular pattern and thin-wall cysts. Equal size of vessel in normal and abnormal areas.

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Fig. 0: Fig.8a. Abnormal expiratory air trapping in a 61-years-old woman with a hypersensitivity pneumonitis to amidarone. Axial thin-slice (1 mm) (a), MIP reformation (b) and mIP reformation (c): lobular air trapping. MIP image (3 mm-thick slab) more clearly demonstrates increased size of vessels in ground-glass which allow diagnosis of mosaic perfusion.

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**Fig. 0:** Fig. 8c. Abnormal expiratory air trapping in a 61-years-old woman with a hypersensitivity pneumonitis to amidarone. Axial thin-slice (1 mm) (a), MIP reformation (b) and mIP reformation (c): lobular air trapping. MIP image (3 mm-thick slab) more clearly demonstrates increased size of vessels in ground-glass which allow diagnosis of mosaic perfusion.

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**Fig. 0**: Fig.9a. Dyspnea in a 28-years-old heavy smoker with obstructive defect. Axial thin-slice images (a,b), axial mIP image (5.8 thick -slab) (c), coronal reformatted (d), coronal mIP image (e). Multiple nodules and cysts with more and less wall thickness (thin arrows). These lesions are distributed in the upper two thirds of the lung. Apical centrilobular emphysema is associated. Mip reformations show a centrilobular artery appearing as a central dot (thick arrow), a finding that is characteristic of centrilobular emphysema and helps differentiate it from cysts. This pattern is highly suggestive of langerhans cell histiocytosis associated to centrilobular emphysema.

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**Fig. 0:** Dysepsia in a 28-years-old heavy smoker with obstructive defect. Axial thin-slice images (a,b), axial mIP image (5.8 thick -slab) (c), coronal reformatted (d), coronal mIP image (e). Multiple nodules and cysts with more and less wall thickness (thin arrows). These lesions are distributed in the upper two thirds of the lung. Apical centrilobular emphysema is associated. Mip reformations show a centrilobular artery appearing as a central dot (thick arrow), a finding that is characteristic of centrilobular emphysema and helps differentiate it from cysts. This pattern is highly suggestive of langerhans cell histiocytosis associated to centrilobular emphysema.

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**Fig. 0:** Fig.10a. Axial thin-slice image (a), axial mIP images (4mm thick -slab) (b). Sub-pleural honeycombing more easily recognized on mIP image.

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Fig. 0: Fig.10b. Axial thin-slice image (a), axial mIP images (4mm thick -slab) (b). Sub-pleural honeycombing more easily recognized on mIP image.

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Fig. 0: Fig.10a bis. Idiopathic pulmonary fibrosis in a 69-year-old man complicated by pneumothorax. Axial thin-slice image (a), axial mIP images (5.7 mm thick -slab) (b,c) clearly demonstrate bronchiolectasis within areas of cysts. The juxtaposed areas of cysts with intervening walls are characteristic of honeycombing.

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**Fig. 0:** Fig. 10b bis. Idiopathic pulmonary fibrosis in a 69-year-old man complicated by pneumothorax. Axial thin-slice image (a), axial mIP images (5.7 mm thick -slab) (b,c) clearly demonstrate bronchiolectasis within areas of cysts. The juxtaposed areas of cysts with intervening walls are characteristic of honeycombing.

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Fig. 0: Fig.10c bis. Idiopathic pulmonary fibrosis in a 69-year-old man complicated by pneumothorax. Axial thin-slice image (a), axial mIP images (5.7 mm thick -slab) (b,c) clearly demonstrate bronchiolectasis within areas of cysts. The juxtaposed areas of cysts with intervening walls are characteristic of honeycombing.

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**Fig. 0:** Fig.11. Tracheal diverticula. Axial mIP image (18 mm thick -slab) showing a rounded air collection located right and posterolateral to the trachea. That air collection is connected to the tracheal lumen by a tiny tracheal wall dehiscence (arrow).

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Fig. 0: Fig.12a. Subglottic stenosis caused by prior intubation (arrows). (a) Coronal oblique mIP (32 mm-thick -slab), (b) Virtual bronchography (volume rendering of the segmented airways) and (c) Descending virtual endoscopy of the trachea shows moderate tracheal stenosis. Severity and craniocaudal length of stenosis were underestimated on axial CT images.

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Fig. 0: Fig. 13a. Extrinsic compression of the trachea by a goiter. (a) Axial thin slice image, (b) coronal oblique mIP image (45 mm thick -slab), (c) Virtual bronchography (volume rendering of the segmented airways after multislice CT acquisition, 1-mm slice thickness) showing the left displacement and abnormal course of the trachea (arrows). The lumen of the trachea is reduced in caliber.

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**Fig. 0:** Fig.13b. Extrinsic compression of the trachea by a goiter. (a) Axial thin slice image, (b) coronal oblique mIP image (45 mm thick -slab), (c) Virtual bronchography (volume rendering of the segmented airways after multislice CT acquisition, 1-mm slice thickness) showing the left displacement and abnormal course of the trachea (arrows). The lumen of the trachea is reduced in caliber.

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**Fig. 0:** Fig.14a. Cystic bronchiectasis in the upper right lobe secondary to tuberculosis. (a) Axial thin-slice image, (b) coronal oblique mIP image (10 mm thick -slab).

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**Fig. 0**: Fig. 14b. Cystic bronchiectasis in the upper right lobe secondary to tuberculosis. (a) Axial thin-slice image, (b) coronal oblique mIP image (10 mm thick -slab).

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**Fig. 0**: Fig.15a. Mucoviscidosis in a 4-year-old girl. (a,b) Axial thin-slice images, (c) axial mIP images (2.5 mm thick -slab), (d) axial MIP images (3.8 mm thick -slab). Diffuse cylindrical bronchiectasis with bronchial wall thickening and mucoid impaction filling bronchiectatic bronchi (arrow). Infectious bronchiolitis (tree-in bud micronodules) is better recognized on MIP images. mIP image shows more easily secondary parenchyma hypoperfusion.

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**Fig. 0:** Fig.15b. Mucoviscidosis in a 4-year-old girl. (a,b) Axial thin-slice images, (c) axial mIP images (2.5 mm thick -slab), (d) axial MIP images (3.8 mm thick -slab). Diffuse cylindrical bronchiectasis with bronchial wall thickening and mucoid impaction filling bronchiectatic bronchi. Infectious bronchiolitis (tree-in bud micronodules) is better recognized on MIP images. mIP image shows more easily secondary parenchyma hypoperfusion.

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Fig. 0: Fig.15d. Mucoviscidosis in a 4-year-old girl. (a,b) Axial thin-slice images, (c) axial mIP images (2.5 mm thick -slab), (d) axial MIP images (3.8 mm thick -slab). Diffuse cylindrical bronchiectasis with bronchial wall thickening and mucoid impaction filling bronchiectatic bronchi. Infectious bronchiolitis (tree-in bud micronodules) is better recognized on MIP images. mIP image shows more easily secondary parenchyma hypoperfusion.

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**Fig. 0:** Fig.16a. Severe asthma associated to hypereosinophily in a 66-year-old male. (a) Coronal oblique mIP image (11 mm thick-slab) and (b) volume rendering of the airways and lung parenchyma showing proximal bronchiecasis (arrows). This pattern is highly suggestive of allergic bronchopulmonary aspergillosis.

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Fig. 0: Fig.17a. Chronic obstructive pulmonary disease (COPD) in a 54-year-old man. (a) Axial thin section CT. (b) Descending virtual endoscopy in the trachea. Typical appearance of saber-sheath trachea.

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**Fig. 0:** Fig.18a. Bronchomalacia in a 56 year-old woman. (a) End-inspiratory image of the trachea is normal. (b,c) Dynamic expiratory CT images demonstrate that the lumen of the trachea and the proximal bronchi are almost completely collapsed (frownlike configuration of proximal trachea). Note that mIP reformation isn't very helpful in this situation.

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**Fig. 0:** Fig. 19. Patient with severe COPD. Coronal oblique reformation on a 4-mm thick slab and minimum intensity projection after MDCT thin collimation acquisition. Note the presence of multiple small air collections in addition to the left main and lobar and segmental bronchial lumens (arrows). They represent outpouchings in the bronchial walls due to dilated submucosal glands.

**Fig. 0:** Fig.20a. Hydatic cyst expelled into the bronchi, image of "a small round bell". (a) Axial thin-slice image, (b) Coronal reformatted mIP image (3-mm thick-slab), (c) Coronal reformatted MIP image (3-mm thick-slab) showing a cavity which had been completely emptied but which contain an opacity in the bottom of the cavity corresponding to the hydatic membrane. Note that mIP reformation is very helpful in this situation to show the bronchus in which the cyst had been ruptured.

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**Fig. 0**: Fig.20b. Hydatic cyst expelled into the bronchi, image of "a small round bell". (a) Axial thin-slice image, (b) Coronal reformatted mIP image (3-mm thick-slab), (c) Coronal reformatted MIP image (3-mm thick-slab) showing a cavity which had been completely emptied but which contain an opacity in the bottom of the cavity corresponding to the hydatic membrane. Note that mIP reformation is very helpful in this situation to show the bronchus in which the cyst had been ruptured.

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Fig. 0: Fig.21a. Post-traumatic trachea rupture. (a) Coronal reformatted mIP image (5-mm thick-slab), (b) axial thin-slab, (c) Coronal oblique reformatted mIP image (26-mm thick-slab), (d) virtual bronchography (Volume rendering of the airways) showing the subglottic anterior rupture (arrows), pneumomediastinum and sub-cutaneous emphysema.

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**Fig. 0:** Fig.21d. Post-traumatic trachea rupture. (a) Coronal reformatted mIP image (5-mm thick-slab), (b) axial thin-slab, (c) Coronal oblique reformatted mIP image (26-mm thick-slab), (d) virtual bronchography (Volume rendering of the airways) showing the subglottic anterior rupture (arrows), pneumomediastinum and sub-cutaneous emphysema.

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Fig. 0: Fig.22a. Left hilar tumor in a 72-year-old man responsible of complete collapsus of the lung. (a) Coronal reformatted image in mediastinum window, (b) Coronal reformatted mIP image in lung window (8.5-mm thick-slab) showing tumor extent to the left main bronchus.

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**Fig. 0:** Fig.23a. Cylindrical bronchiectasis and infectious bronchiolitis in a 6-year-old female. (a) Axial thin slice, (b) coronal reformatted MIP image, (c) coronal mIP image. Small centrilobular nodular and linear branching opacities (tree-in-bud sign) are visible in the lower lobes. Micronodular profusion is much better detected with MIP reformation.

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Fig. 0: Fig.24a. Dyspnea following surgical treatment of a ruptured hydatic cyst in the bronchi. (a) Axial thin slice, (b) coronal reformatted image, (c,d) axial and coronal MIP images (3.5-mm thick-slab) Small, ill-defined centrilobular nodules, homogeneously and diffusely distributed throughout the lungs, this is a pattern highly suggestive of hypersensitivity pneumonitis secondary to hydatic liquid inhalation.

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Fig. 0: Fig.25a. Constrictive bronchiolitis in a 56-year-old woman. (a) End-inspiratory Axial mIP image (3.8 mm-thick-slab). (b) Dynamic expiratory axial mIP image (2.4 mm-thick-slab). Abnormal expiratory air trapping. Postexpiratory image shows larger vessels in areas of high attenuation. This pattern corresponds to a mosaic perfusion. Note associated Pulmonary arterial hypertension.

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Conclusion

- Multi-detector row CT of the chest has revolutionized the evaluation of diffuse lung disease.
- Two-dimensional reformatted images are now of equal importance with the 2D axial images in making the final diagnosis.
- mIP is the tool of choice for the detection, assessment of distribution, evaluation of extent, and characterization of linear or ground-glass attenuation and mosaic perfusion.
- MIP allows the recognition of pulmonary edema in cases of linear attenuation associated with enlarged pulmonary veins.
- Moreover, mosaic perfusion may be differentiated from mosaic attenuation on the basis of vessel size.
- MIP permits the detection and characterization of micronodules and differentiation between perilymphatic, miliary, and centrilobular distribution.
- MIP can also help differentiate between constrictive bronchiolitis and mixed emphysema.
- In the future, 3D reformatted images could be used to quantify these diffuse disorders.
References


