Functional Imaging
Computed Tomography and MRI

Saeed Mirsadraee, MD, PhD, Edwin J.R. van Beek, MD, PhD*

KEYWORDS

• CT • Airways • Parenchyma • Ventilation • Perfusion • Computer-aided detection • Lung function • MRI

KEY POINTS

- Standard imaging for the lungs has limited specificity, does not always diagnose pathology at a treatable stage, and does not provide physiologic information.
- In the past decade, advances in imaging technology and analytical methods allowed more physiologic approach in lung imaging, functional imaging.
- Novel CT and MRI techniques, such as ventilation and perfusion, have been developed in imaging of the lungs.

INTRODUCTION

Since the previous review on this topic of functional computed tomography (CT) and MRI of the lung, significant advances have been made into the development of imaging based biomarkers for evaluation of lung diseases.[1] The increased utility of multidetector row CT (MDCT) has incorporated traditional high-resolution lung imaging, allowing multiplanar reconstructions at hitherto unimaginable spatial resolution. The incorporation of contrast-enhanced CT methodologies is still expanding, thereby not just yielding us the capacity to study vascular pathology in great detail, but, in combination with greater speed and coverage of the chest, also bringing us closer to true lung perfusion in clinical practice. Techniques like spirometry-controlled MDCT have paved the way for introduction of routinely applicable protocols where patients are monitored more closely and coached to obtain better quantifiable CT imaging data. In addition to these parenchymal and vascular imaging improvements, inhaled contrast has also continued further development and xenon gas is now being piloted in patients with a range of lung pathologies. Last, but not least, software has continued to develop, enabling quantification of parenchymal disease, quantification of ventilation–perfusion ratios and giving us insights into airway disease like never before.

In the meantime, MRI is beginning to overcome its problems related to lung imaging (mainly field inhomogeneity and lack of protons in the lung), both with applications of proton MRI sequences as well as by using injected (gadolinium-based) and inhaled (oxygen, hyperpolarized gases such as ^{3}He, ^{129}Xe, and ^{19}F) contrast methods. These advances are starting to make an impact on the management of particularly radiation-sensitive patients (children, pregnancy, those with chronic conditions requiring repeated investigations) and in areas where CT is disadvantaged in providing soft tissue detail (eg, lung cancer staging in the lung apex, mediastinal involvement, and chest wall assessment). The faster imaging speed also allows MRI to give a comprehensive assessment of the effects of heart and lung pathologies on each organ system. Although some of these techniques were limited initially to a few centers, there is now a gradual expansion of knowledge making these technologies more widely available.

Disclosure: None.
Clinical Research Imaging Centre, Queen's Medical Research Institute, University of Edinburgh, 47 Little France Crescent, Edinburgh EH16 4TJ, UK
* Corresponding author.
E-mail address: edwin-vanbeek@ed.ac.uk

Clin Chest Med 36 (2015) 349–363
http://dx.doi.org/10.1016/j.ccm.2015.02.014

This article describes the new applications of CT and MRI in relation to obtaining functional and quantifiable tools for the study of pulmonary parenchymal and vascular disorders. We hope that it will familiarize the community with the translation of techniques from research into clinical applied methodologies.

COMPUTED TOMOGRAPHY

Computed Tomography Hardware Systems Developments

As described, CT has developed rapidly into one of the most clinically requested investigations in medicine.[1] A recent review of the history and development of CT on the occasion of the centenary meeting of the Radiological Society of North America is worth reading in this context.[2] Clearly, much progress has been made as we have moved from the dynamic spatial reconstructor, the prototype of dynamic volumetric x-ray CT designed and installed at the Mayo Clinic in the mid 1970s.[3] From the initial beginnings of computed transverse axial scanning tomography,[4] via electron beam CT[5] to the current 16-cm coverage electrocardiography-gated imaging within a single heartbeat,[6] CT has been at the heart of changes in medical diagnosis and management. It is difficult to imagine that even Hounsfield in his visionary acceptance speech of the Nobel Prize could have quite foreseen the impact CT has made.[7]

Apart from the high temporal resolution now available on CT systems, the spatial resolution has also improved and 0.4-mm isotropic resolution is now achievable using the latest scanner technology.[8] Furthermore, the application of novel reconstruction methods has resulted in significant reductions in radiation dose, and all vendors now routinely include iterative reconstruction as part of their standard protocols with the latest techniques resulting in very low-dose CT with exposure for lung parenchymal disease in the order of 0.15 mSv[9] and for lung nodule detection with exposures less than traditional chest radiographs at 0.06 mSv.[10]

These developments have had both positive and negative impacts on the application of CT. The surge in use of CT has resulted in a significant increase in radiation burden in the overall population,[11,12] although it is important to realize that the use of CT has a greater benefit to patients, which justifies its risks.[13] Moreover, radiation exposure is now being addressed by stricter guidance on indications and monitoring of radiation dose.[14] Furthermore, novel reconstruction methods, such as iterative reconstruction, have allowed introduction of dose limitation while maintaining signal-to-noise ratio and image quality. Another issue with different scanner manufacturers and different reconstruction techniques is that this has an effect on density measurements, and this may impact on interpretation of images and the use of different CT systems in cohort and clinical studies.[15,16]

The advanced technologies now enable structural imaging of the chest in great detail and with 0.4 to 0.6 mm isotropic resolution. This is all achieved with a *z*-axis coverage of 4 to 16 cm in a rotation time of 0.3 seconds or less. This speed makes the examination more robust and full coverage of the chest in a single breath-hold is easier to achieve. At the same time, it is crucial to coach patients to full inspiration as well as forced residual volume expiration where air trapping or airway collapse is being investigated.

The application of contrast has yielded anatomic images of the vasculature in the chest, including the coronary arteries, aorta, and pulmonary vessels. However, with dual-energy application, where 2 scans are performed using different keV settings, it is feasible separate out particular high-density compounds such as iodine or xenon. Thus, it is now feasible to obtain the distribution of vascular contrast (resulting in a measure of pulmonary blood volume),[17,18] as well as to evaluate the distribution of inhaled contrast like xenon gas.[19,20] Similarly, dynamic contrast-enhanced methods are able to track a tight contrast bolus of 5 to 9 mL/s during a 20-second period to yield true perfusion, mean transit times (MTT) and even assess pulmonary and systemic supply of the pulmonary vascular bed.

Clearly, the versatility of CT is expanding as the radiation dose, and temporal and spatial resolution are all optimized. This expansion will give impetus to the development of more individual approaches, with a combination of morphologic and functional information. However, radiation will always need to be a matter of concern and, despite these developments, we need to take into consideration that MRI may be preferred wherever the information gained can be on a similar setting compared with CT. For future studies, it is very likely that there will be an interleaved approach to ordering MRI and CT investigations in patients where longitudinal studies are required.

Quantitative Image Analysis and Distilling Functional Information

Quantification of disease using CT methods depends on a number of fundamental steps: protocol standardization, coaching of patients during