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Aquilion ONE

TOSHIBA

Leading Innovation >>>

Lung Perfusion Analysis

New Pathways in Lung Imaging

Aquilion ONE

dynamic volume CT

Case Study Brochure

PLA 309 Hospital

Lung Perfusion Analysis

New Pathways in Lung Imaging

Introduction

PLA 309 Hospital in Beijing, China, is an 1800-bed hospital that is a member of the group of hospitals operated by the People's Liberation Army (PLA) to provide care for army personnel and their dependents. Established in 1958, PLA 309 is a multidisciplinary hospital offering a wide range of medical services, and it is particularly notable as the leading transplant center in the PLA hospital system. Approximately 400 renal transplantations and more than 100 liver transplantations are performed at our institution annually. In addition, a specialized Tuberculosis Institute with 200 beds provides dedicated care and treatment for patients suffering from this condition.

The radiology department performs all of the imaging services required in a modern hospital, with a variety of X-ray rooms, ultrasound systems, one MRI scanner, one DSA room, and three CT scanners. In August 2010, an Aquilion ONE™ dynamic volume CT scanner was installed at our hospital, which routinely performs an average of 50 CT studies a day. A wide range of examinations are performed using this CT scanner, from routine examinations to 4D dynamic volume perfusion studies.

Taking advantage of the unique dynamic volume scan mode available in the Aquilion ONE, we have developed an imaging protocol in which the volumetric perfusion analysis software is used for the evaluation of lung disease. Of particular interest is the assessment of patients with chronic tuberculosis presenting with hemoptysis, in whom dynamic perfusion analysis readily identifies arterio-pulmonary fistulas. The morphological and functional information provided by these scans has dramatically improved our ability to evaluate and treat these patients.

This brochure presents some examples of our work with dynamic volume lung perfusion studies.

Dr. G. Ao, Director
Interventional Radiologist
PLA 309, Beijing, China

Dr. X. Yuan, Deputy Director
Radiologist with special interest in CT Perfusion, PLA 309, Beijing, China

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Rationale for studying lung perfusion with the Dual Input Maximum Slope model

The lungs, like the liver, have a dual-input vascular supply. The pulmonary circulation via the pulmonary arteries (PA) is for gas exchange with the alveoli, and the bronchial circulation via the bronchial arteries (BA) supplies the lung parenchyma itself.

In lung perfusion studies, either a single-input or dual-input analysis algorithm is selected depending on the focus of the examination. If the study is focused on pulmonary perfusion, single-input analysis using the PA as the arterial input will yield accurate results. When evaluating lung masses, it is necessary to consider the possible underlying pathology and its blood supply. For example, in small metastatic lung nodules and bronchial alveolar carcinoma, the blood flow is assumed to be from the PA, at least initially, and single-input analysis can be applied with the PA as the arterial input. For other masses, the fraction of BA flow supplying the mass increases and may indeed become the dominant blood supply, and it is therefore necessary to apply a dual-input analysis method utilizing both the PA and the BA (or aorta) as input functions. Clearly, a dual-input model is more appropriate for studying vascular malformations and infections, possibly with associated fistula formation and shunting between the systemic and pulmonary arterial systems. At PLA 309 Hospital, Dr. Ao and Dr. Yuan have conducted a study to assess the feasibility and reproducibility of Toshiba's Dual Input Maximum Slope analysis software in the evaluation of lung perfusion. Their primary outcome suggests that applying the Dual Input Maximum Slope model to the lung is feasible and provides reproducible results, and that this model can also identify the input blood supply fractions, which cannot be obtained by Single Input Maximum Slope analysis.

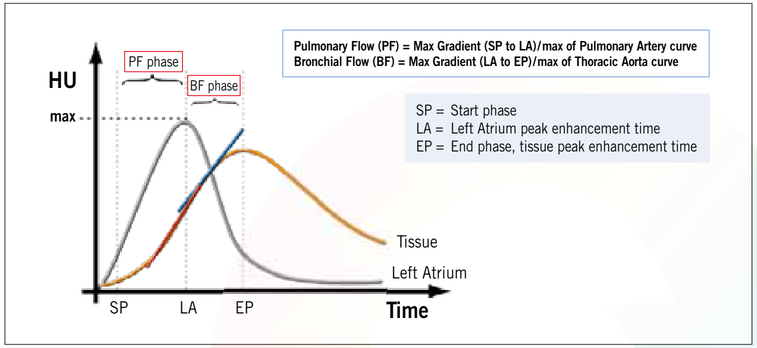
Applying the Dual Input Maximum Slope algorithm in lung perfusion studies

When evaluating lung perfusion, care must be taken to include the lung hilum in the volume during scan planning. The time-density curves (TDCs) for the pulmonary artery and the thoracic aorta are generated by placing ROIs in the pulmonary artery trunk and the thoracic aorta. The thoracic aorta serves as a substitute for the bronchial arteries or other systemic vessels supplying the lung parenchyma because they all arise from the thoracic aorta. The TDC of the left atrium is generated by placing a ROI in the left atrium. The tissue TDC is generated by placing a ROI either in the mass or in peripheral lung parenchyma. The peak enhancement time of the left atrium divides the tissue TDC into a pulmonary artery perfusion phase and a bronchial artery perfusion phase. The range of analysis is restricted to the soft tissues for the evaluation of soft tissue masses and to the lung tissues for assessment of the lung parenchyma.

Soft Tissue Range: Maximum = 150 HU, Minimum = –80 HU. The tissue ROI is placed in the target mass to generate the tissue TDC.

Lung Parenchyma Range: Maximum = 0 HU, Minimum = –1000 HU. The tissue ROI is placed in peripheral normal lung parenchyma to generate the tissue TDC.

The respective blood flow is calculated as shown below.



The outputs are PF (ml/100 ml/min), BF (ml/100 ml/min), and perfusion index (PI%). PI = (PF/PF+BF)%, which is the percentage pulmonary artery perfusion.

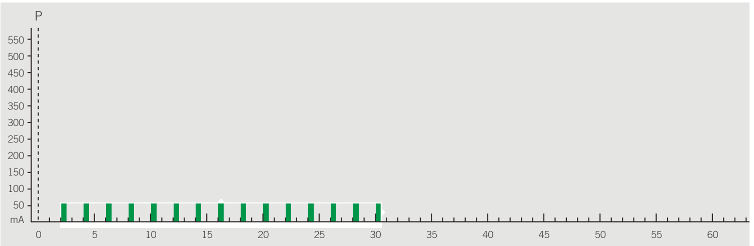
Lung Perfusion Protocol Guide

The Scan Protocol

The Lung Perfusion protocol is used to evaluate medical conditions in which it is necessary to assess bronchial blood flow as well as pulmonary blood flow. Examples of such conditions include lung masses and hemoptysis due to tuberculosis. Dual Input Maximum Slope postprocessing is performed. The parametric maps obtained show pulmonary flow (PF), bronchial flow (BF), and the pulmonary perfusion index (PI), where PI is the percent pulmonary perfusion.

The TDCs of the pulmonary artery and bronchial artery are sampled, and the target lung tissue is sampled until maximum enhancement is reached.

Lung Perfusion protocol outline:



The Lung Perfusion protocol summary:

Operation Mode	kV	mA	Rot. Time	Sample Time	Acquisition Interval	SUREIQ™
Intermittent	100 kV	60	0.5 s	2-30 s	2	Body Perfusion

AIDR 3D is included in Body Perfusion SUREIQ as shown below. Toshiba international application specialists can help you create SUREIQ and Lung Perfusion protocols.

SUREIQ	FC	Dose Reduction	OSR	Filter
Body Perfusion	17	AIDR 3D Standard	Body	OFF

Injection Guidelines

Lung Perfusion requires the use of contrast medium with an iodine concentration of at least 350 mgI/mL. The following contrast injection protocol has been optimized for Lung Perfusion. Due to the high injection rates, an 18G or larger IV cannula is placed in a right antecubital vein. The saline flush is needed to ensure that all contrast medium arrives at the heart promptly.

Lung Perfusion contrast injection chart:

Body Weight (kg)	Injection Rate (mL/s)	Contrast Volume (mL)	Saline Flush (mL)
<50	5.0	30	50
50-90	6.0	40	50
90<	7.0	50	50

Dose Management

The dynamic volume scans, which are mainly used for functional analysis, can be acquired with significantly lower radiation exposure than needed for routine diagnostic studies. The Lung Perfusion scan protocol and analysis software have therefore been optimized for low-dose parameter settings.

In addition, the number of volume acquisitions is adjusted according to the lung pathology, with the sampling time optimized to ensure accurate quantification of blood flow dynamics.

Toshiba is continuously striving to promote the principle of ALARA. The recent release of AIDR 3D has enabled a dose reduction of approximately 40% for all Body Perfusion protocols. AIDR 3D is Toshiba's iterative reconstruction solution that has been fully integrated into the Aquilion ONE system to ensure efficient workflow.

The dose for the Lung Perfusion protocol is shown for a patient of average size (80 kg man), assuming a 16 cm scan range and 15 volumes at 100 kV and 30 mAs:

Protocol	DLP mGy·cm	mSv
Lung Perfusion	462.0	6.47 (k = 0.014)

While the dose reduction with AIDR 3D, at 40%, is significant in itself, the actual dose of 6.47 mSv places the Lung Perfusion protocol in the same dose range as routine diagnostic CT studies. Optimization of the protocol is ongoing and is expected to result in even further dose reduction.

Small Cell Carcinoma

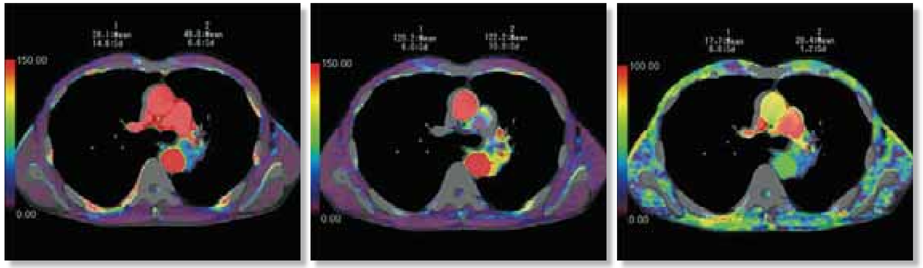
Patient History

This 55-year-old man was referred for CT following a chest X-ray that showed a mass in the hilum of the left lung. 4D Lung Perfusion was performed to further assess the mass.

Findings

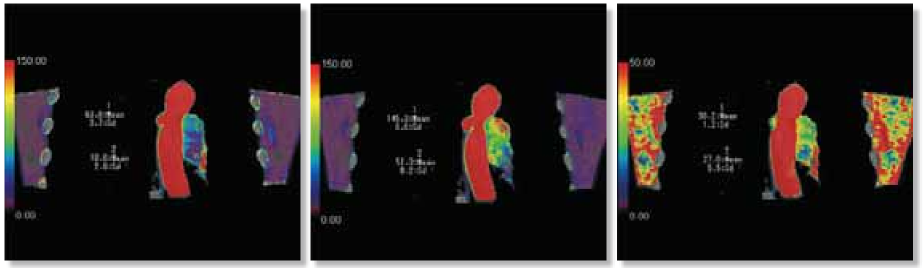
Soft tissue analysis

Pulmonary Flow (PF) | Bronchial Flow (BF) | Perfusion Index (PI)



The mediastinal mass is adjacent to the left main bronchus, descending aorta, and primary branches of the left pulmonary artery. The two ROIs are placed anterior and posterior to the superior pulmonary artery branch. The PI values are ROI 1 = 17.7 and ROI 2 = 28.4, demonstrating dominant bronchial artery flow to the mass at more than 70%.

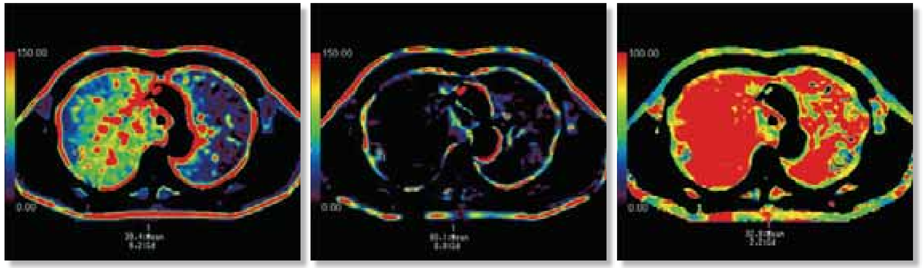
PF | BF | PI



In the coronal plane, the heterogeneous nature of the mass is clearly seen in the BF and PI maps. ROI 1 and ROI 2 are placed in a high-BF area and a low-BF area, respectively. The PI values are ROI 1 = 30.2 and ROI 2 = 27.0, demonstrating dominant bronchial artery flow of at least approximately 70%, with higher values elsewhere in the mass.

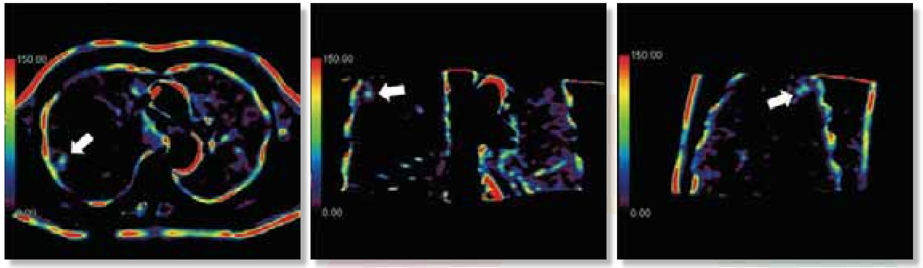
Lung tissue analysis

PF | BF | PI



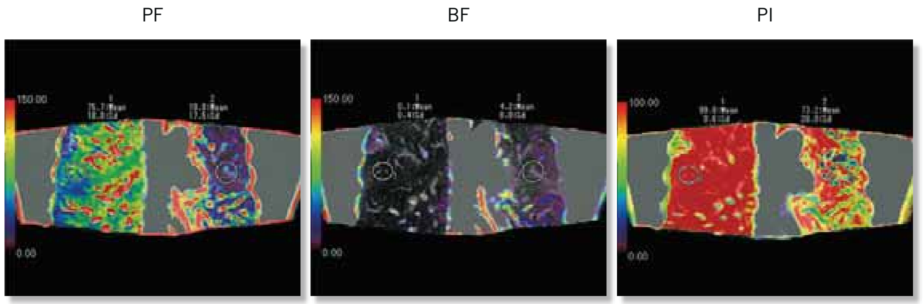
A suspicious nodule in the right upper lobe was identified. The ROI in the nodule shows PF = 39.4, BF = 80.1, and PI = 32.9%, with dominant bronchial artery flow in the nodule at 67.1%.

Axial | Coronal | Sagittal

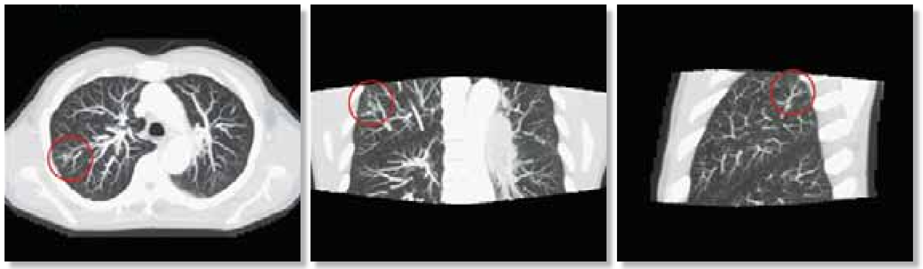


The body perfusion software allows the maps to be viewed in the three standard planes. These images are of the BF map. The BF map can clearly depict small nodules, as seen in this case (arrows). No other nodules are observed.

Small Cell Carcinoma (continued)

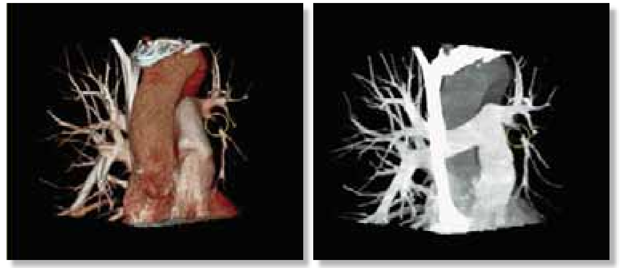


The coronal plane maps demonstrate a dramatic reduction in the pulmonary artery perfusion of the left lung compared to the right lung. The PI map shows ROI 1 = 99.8% in the right lung and ROI 2 = 73.2% in the left lung.



Toshiba's intuitive analysis software permits 4D viewing of the same dataset. These MIP images clearly show the suspicious nodules in the posterior segment of the right upper lobe (red circles).

These soft tissue MIP images show the mass compressing the left pulmonary artery and primary branches. The result is a significant reduction in pulmonary artery perfusion of the entire left lung, as shown in the coronal perfusion map of the lung parenchyma.



These 3D images confirm that the inferior left pulmonary artery is compressed by the tumor (circles).

Conclusion/Treatment

Biopsy of the mass was performed, and cytological analysis showed poorly differentiated small cell carcinoma. The patient was referred for chemotherapy and radiotherapy.

CASE 2

Squamous Cell Carcinoma

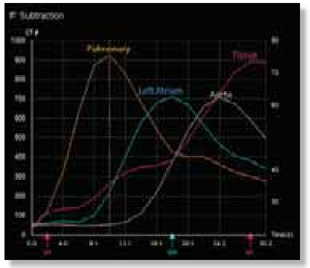
Patient History

This 50-year-old man presented with a mass in the left lung detected by chest X-ray. He was referred for CT for further imaging and staging. 4D Lung Perfusion was performed to assess the mass.

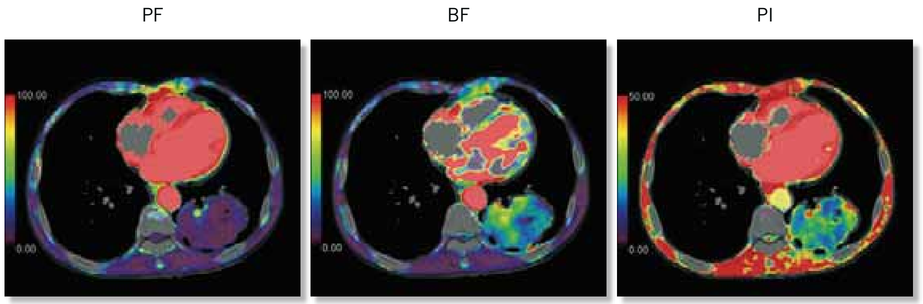
Findings

Soft tissue analysis

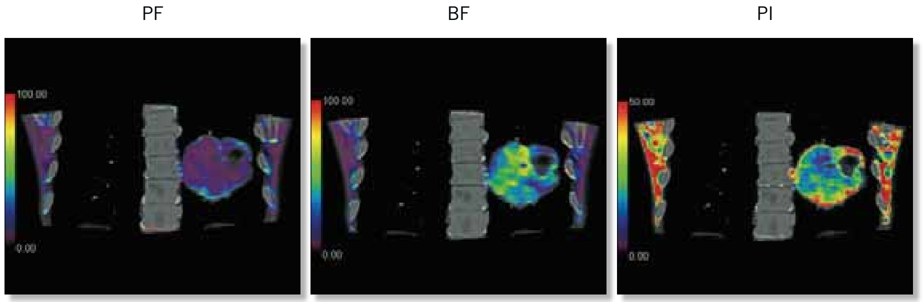
ROIs were placed in the pulmonary trunk, left atrium, aorta, and the mass itself. The time-density curves (TDCs) shown below were used for Dual Input Maximum Slope perfusion analysis.



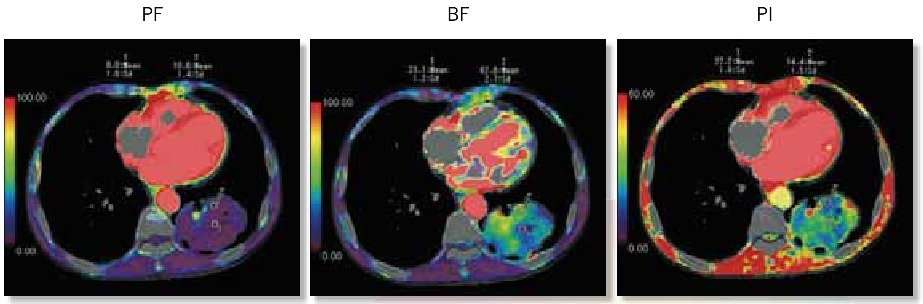
The tissue TDC shows two distinct slopes reflecting pulmonary artery and bronchial artery enhancement (aorta). The two enhancement patterns are neatly separated by the peak enhancement time in the left atrium.



The resulting pulmonary flow (PF) and bronchial flow (BF) maps permit the comparative visual assessment of perfusion within the mass. In this case, decreased PF and increased BF are clearly observed. The BF and PI maps show that the perfusion of the mass is heterogeneous. It is thought that the areas of high BF correspond to tissues with high levels of angiogenesis and that the areas of low BF correspond to tissues that have progressed all the way to the end stage of necrosis and cavity formation, which is also present in this mass.



The mass and its relations can be evaluated in the three standard planes: axial, sagittal, and (as in these images) coronal.



ROI 1 is placed in a low-BF area and ROI 2 is placed in a high-BF area. The ROIs are synchronized by the software to the same anatomy in the corresponding PF and PI maps. The PI map shows the respective PF fractions to be 27.3% and 14.4%. This pattern of dominant BF of more than 70% is consistent throughout the mass, indicating very little blood flow from the pulmonary artery circulation.

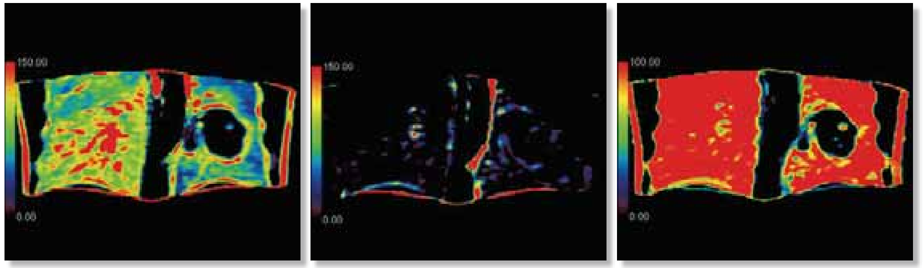
Squamous Cell Carcinoma (continued)

PF BF PI

An enlarged lymph node in the aorto-pulmonary window is identified in the fusion CT image. It shows very high BF and very low or no PF, as would be expected. No other lesions are observed.

Lung tissue analysis

PF BF PI



The lung parenchyma can be assessed using the same data by simply changing the analysis range from soft tissue to lung tissue. In this case, the tissue ROI is placed in peripheral normal lung parenchyma. Care must be taken to avoid large vessels and the fissures. The bronchial flow map can show small nodules excluded from the soft tissue analysis range. In this case, no small nodules are observed.

Conclusion/Treatment

Biopsy of the mass was performed, and cytological analysis showed squamous cell carcinoma. The patient underwent surgery to resect the left lower lobe.

Hemoptysis

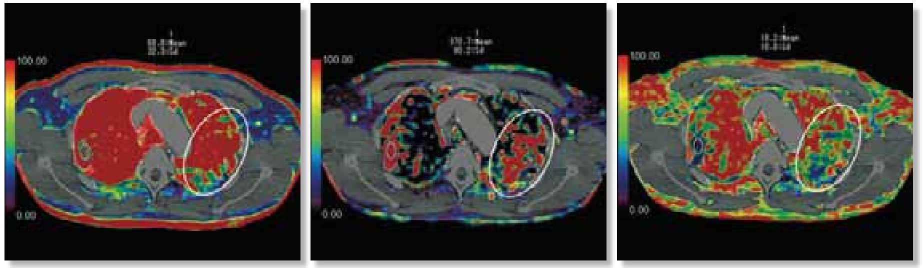
Patient History

This 43-year-old man with a history of chronic tuberculosis presented with hemoptysis. 4D Lung Perfusion was performed to identify and localize any fistulas.

Findings

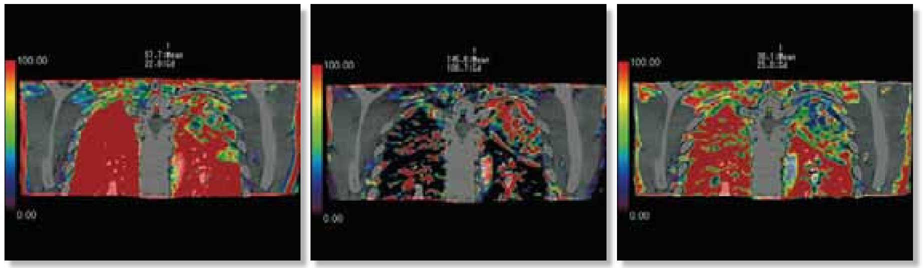
Lung tissue analysis

PF BF PI



These axial maps at the level of the aortic arch demonstrate a very large apical fistula in the left lung (white ellipse). The small ROI 1 in the left apical fistula shows PF = 68.8, BF = 370.7, and PI = 18.2, exhibiting the typical pattern of reduced PF and increased BF seen in fistulas. The mottled appearance of the BF and PI maps indicates multiple areas of fistula formation at this level in both lungs.

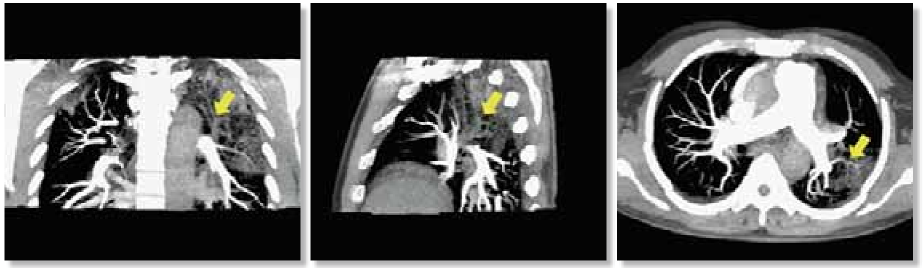
PF BF PI



In these coronal plane maps, the ROI is placed in the area of the left apical fistula. The perfusion measurements are PF = 57.7, BF = 145.6, and PI = 38.1. The BF map clearly indicates an abnormal increase in the bronchial flow fraction due to the systemic-PA shunting.

4D MPR viewing

Pulmonary artery phase



These MIP images in the peak pulmonary artery phase show no enhancement of the pulmonary arteries (arrows) in the region of the lung corresponding to the left apical fistula.

Peak aortic phase

These images in the peak aortic phase show late enhancement of multiple pulmonary artery branches in the region corresponding to the left apical fistula (yellow arrows). Significant systemic-PA shunting is seen, with reverse PA flow. Shunting is also observed in the region corresponding to the right apical fistula (red arrow), but not to the same degree as for the left apical fistula.

Hemoptysis (continued)

Treatment

Digital subtraction angiography (DSA)

• Right lung

1 2 3

Image 1 shows that the right apical fistula is fed by the 3rd intercostal artery (circle). The pulmonary shunt (arrow) is demonstrated in image 2, which shows the selective catheterization of the 3rd intercostal artery. Image 3 shows the vessel post embolization. No other shunts are identified in the right lung.

• Left lung

1 2

Image 1 shows a tortuous apical branch of the left 5th intercostal artery with staining in the region of the fistula. There are many small vessels in the fistula bed, but no BA-PA shunts are identified. Image 2 shows the left 5th intercostal artery post embolization. Since the perfusion study showed that shunting was definitely present within the left apical fistula, another source of systemic blood flow to the fistula was sought.

3 4 5

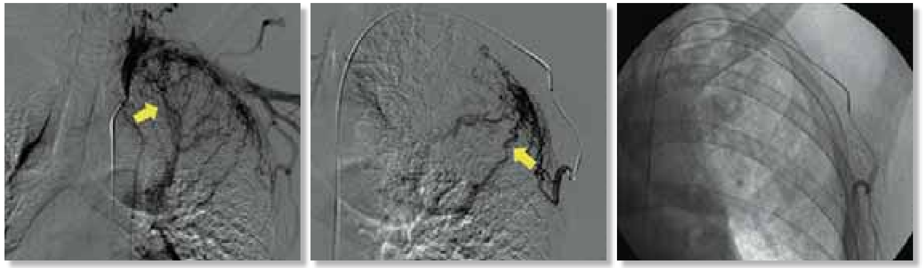


Image 3 shows a large fistula with shunts opacifying the pulmonary arteries (arrows). The feeding arteries were identified as a branch of the left inferior thyroid artery and the left lateral thoracic artery. Image 5 shows the left lateral thoracic artery post embolization.

6 7

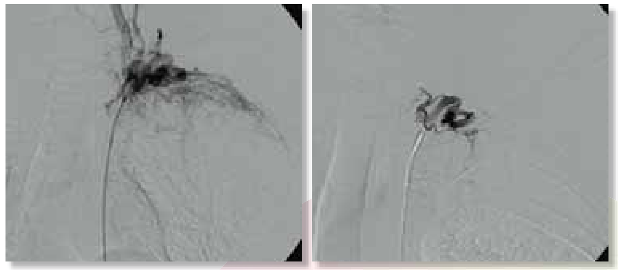


Image 6 shows the selective catheterization of the thyroid artery feeding the fistula bed. Image 7 shows the artery post embolization.

Conclusion

Lung Perfusion correctly identified and localized the fistulas as seen in the DSA procedure.
“Lung Perfusion localizes the fistula before DSA. As a result, less time is needed to search for the feeding artery during the DSA procedure. This reduces the total radiation dose to the patient.” — Dr. Ao

Chronic Tuberculosis

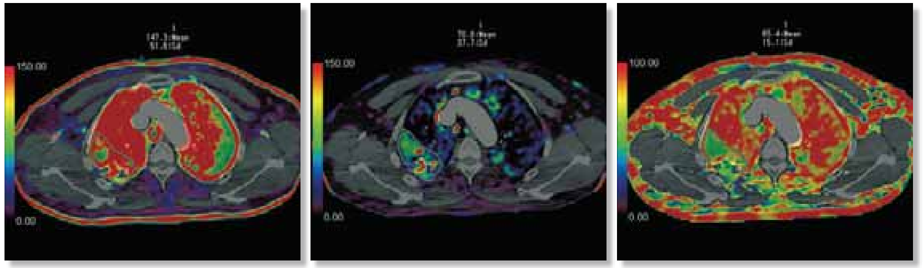
Patient History

This 54-year-old man with a history of chronic tuberculosis presented with hemoptysis. Lung Perfusion was performed to identify and localize the fistula before a planned DSA procedure.

Findings

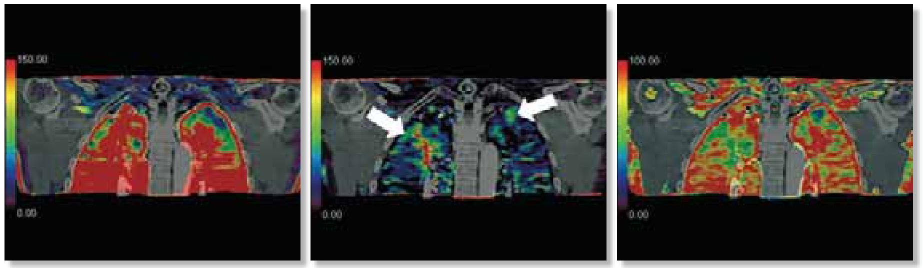
Lung tissue analysis

PF BF PI



In these axial maps, a ROI is drawn around the large fistula in the apex of the right lung. The ROI in the fistula shows PF = 147.3, BF = 70.8, and PI = 65.4. There is a decrease in the pulmonary artery flow fraction (65.4%) and an increase in the bronchial artery flow fraction (34.6%), demonstrating the effect of the hemodynamic BA-PA shunting. Both upper lobes show the mottled appearance typical of increased BF and decreased PF, which indicates the formation of multiple small fistulas.

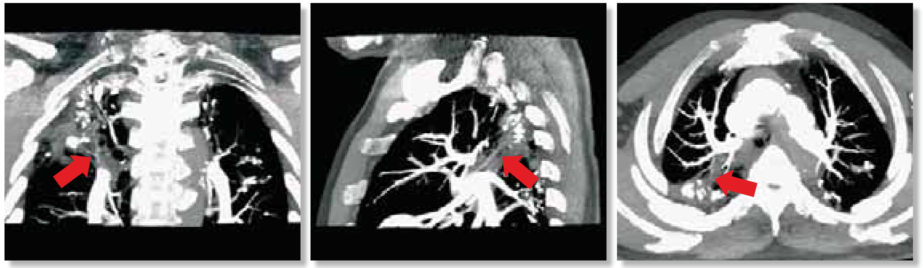
PF BF PI



Panning through the lungs in the coronal plane shows that the apex of both upper lobes is affected. The fistula focus on the right is much larger than that on the left (arrows).

4D MPR viewing

Pulmonary artery phase



These MIP images in the early pulmonary artery phase show no enhancement of the pulmonary artery branches in the right lung corresponding to the area of the fistula (arrows).

Peak aortic phase

These MIP images in the aortic phase show late enhancement of the pulmonary artery branches corresponding to the area of the fistula (arrows). These pulmonary branches demonstrate the BA-PA shunt causing reverse flow due to the higher pressure in the BA.

Chronic Tuberculosis (continued)

Treatment

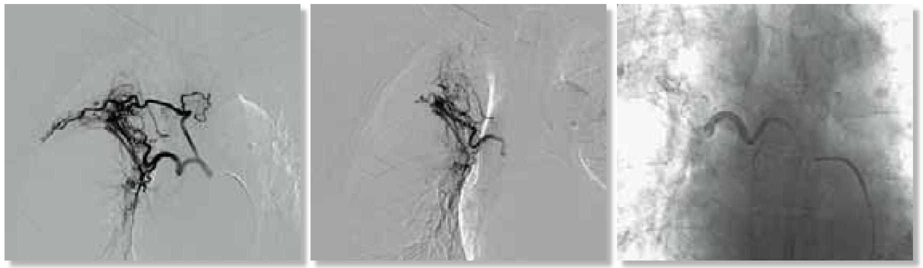
Digital subtraction angiography (DSA)

• Right lung

1 2 3

Image 1 shows the right bronchial artery and the 3rd intercostal artery sharing a common trunk. Fistula formation (black arrow) and the BA-PA shunt (red arrow) are clearly seen.

4 5 6



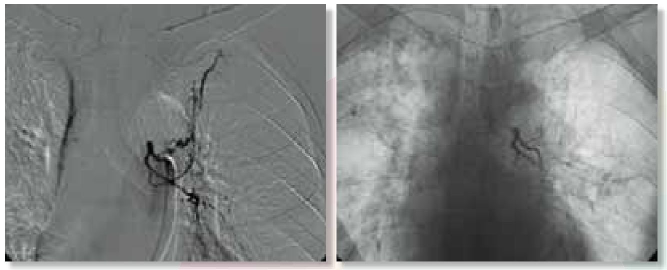
These DSA images show the selection and embolization of the right bronchial artery.

7 8 9

Following embolization of the right bronchial artery, there are still small vessels from the 3rd intercostal artery feeding the fistula bed, as shown in image 7 (black arrows, red arrowheads). Images 8 and 9 show the selection and embolization of the 3rd intercostal artery.

• Left lung

1 2



The left bronchial artery is seen feeding the left apical fistula (image 1) and is identified post embolization (image 2). Other systemic vessels were observed feeding both vascular beds and the embolized area (not shown).

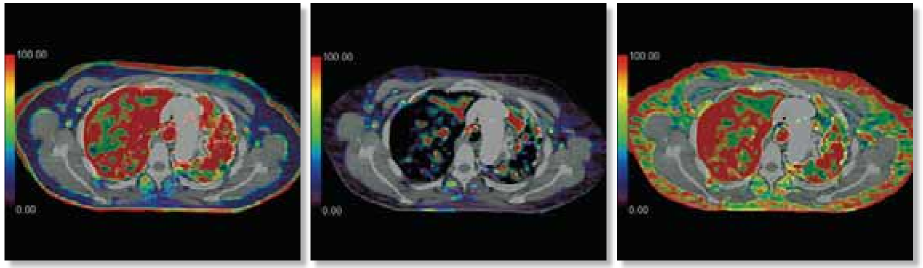
Massive Hemoptysis

Patient History

This is a 48-year-old woman with a history of tuberculosis who presented with massive hemoptysis.
Lung Perfusion was performed prior to digital subtraction angiography.

Findings

PF BF PI



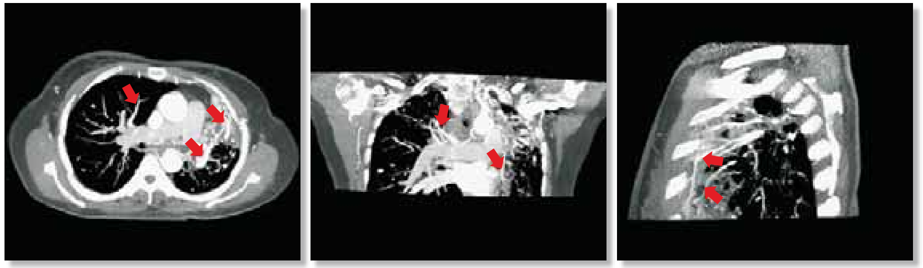
Panning through the lungs in all planes showed extensive fistulas in both lungs. The mottled appearance seen in all the maps, including these axial images, demonstrates numerous fistulas with the characteristic pattern of a reduced PF and a corresponding increase in BF.

PF BF PI

These coronal maps show abnormal perfusion of the entire left lung due to extensive fistula formation. A large fistula is also seen in the right apical segment (ellipses).

4D viewing

Axial Coronal Sagittal



These MIP images in the peak aortic phase demonstrate multiple systemic-PA shunts in both lungs (arrows). There are also anterior intercostal artery shunts, best seen in the sagittal image.

Massive Hemoptysis (continued)

Treatment

Digital subtraction angiography (DSA)

• Right lung

1 2 3

Image 1 shows the large fistula in the apical segment of the right lung. There are also smaller fistulas in the right middle lobe (arrows). Image 2 shows that the right 1st and 2nd intercostal arteries originate from the right bronchial artery trunk (arrows). Although the intercostal arteries were not directly involved in the fistula, it was considered that there was a risk of subsequent fistula formation with the existing fistula bed which might lead to recurrence of the shunt and hemoptysis. Therefore, the right BA trunk was embolized with a coil as shown in image 3.

• Left lung

1 2 3

Image 1 shows the left bronchial artery feeding into a complex fistula bed. Image 2 shows partial embolization and image 3 shows total embolization of the vessel.

4 5 6

A second left bronchial artery was identified. The artery was found to be enlarged and tortuous as shown in image 4. It was embolized distally with Gelfoam and proximally with a coil as shown in images 5 and 6.

7 8 9

This series of images shows enlarged anterior intercostal arteries arising from the left internal mammary artery and feeding into the fistula bed (red arrows). In image 8, the left main pulmonary artery trunk (yellow arrow) is opacified, indicating associated shunting. The anterior intercostal arteries were selectively embolized. Image 9 shows the selection and embolization of the most proximal intercostal artery.

Conclusion

This was a complex case with multiple systemic arteries feeding into the fistulas and shunts in both lungs. All of the arteries involved were identified and embolized (not all are shown). Lung Perfusion accurately depicted the extent of the extensive fistulas and shunts, and none of the abnormalities seen in DSA were missed by Lung Perfusion.