Dyspnea is the major symptom experienced by patients with heart failure (HF) and points to the important role of the lungs in this syndrome.

Normal left ventricular diastolic function keeps the left atrial and pulmonary venous pressures low (<12 mm Hg), both at rest and during submaximal exercise.1 With this normal low pulmonary venous pressure, only a small amount of fluid and protein are filtered through gaps in the pulmonary capillary endothelial cells and into the alveolar interstitial space because the hydrostatic pressure is mostly offset by the protein osmotic pressure.2 Thus, normally the small amount of fluid and protein entering the interstitial space is cleared by lymphatic drainage into the venous circulation.

An elevation of left ventricular diastolic and pulmonary venous pressures is a characteristic of HF, regardless of the ejection fraction.3 Mild elevations of pulmonary venous pressure (18–25 mm Hg) increase the flow into the interstitial space.2 When this flow exceeds the clearance ability of the lymphatics, edema accumulates in the lung interstitial space. This can be seen on a chest x-ray as Kerley B lines. The accumulation of interstitial fluid enhances the stiffness of the lungs, leading to an increase in work required to breathe, and produces the perception of dyspnea. With higher pulmonary venous pressures (>25 mm Hg), the accumulating fluid enters the alveolar space, producing pulmonary edema. This interferes with gas exchange and results in intrapulmonary shunting, leading to hypoxia. In this way, acute pulmonary edema can produce life-threatening respiratory failure.

Chronic elevation of pulmonary venous pressures, as occurs in mitral stenosis, stimulates fibrosis, which decreases fluid transudation. This impairs pulmonary function, but makes it possible for some patients to chronically tolerate high pulmonary venous pressures without developing overt pulmonary edema.4

The elevated pulmonary venous pressure in HF also increases the pressure in the pulmonary arteries, both due to the passive effects of increased downstream pressure and due to pulmonary vasoconstriction.5,6 In addition, the elevated pulmonary venous pressure contributes to the pulsatile load, raising systolic pulmonary artery pressure.7 The resulting pulmonary hypertension increases the load on the right ventricle, contributes to exercise intolerance, and indicates a poor prognosis.

The study by Cao et al8 in this issue of Circulation: Cardiovascular Imaging used an innovative magnetic resonance technique to provide detailed information on the important interaction of the heart and lungs in HF. Using gadolinium first-pass perfusion imaging, the time variations in signal intensity were converted to a contrast concentration time curve. With the assumption that pulmonary perfusion is a linear system, indicator dilution theory was used to assess the pulmonary blood flow by assessing the maximum signal intensity and the time course of the signal change. The rate of blood flow (perfusion) into small regions of the lung was determined by directly deconvolving the measured blood enhancement signal and the measured tissue enhancement signal to estimate the impulse response function, \( h(t) \). A quantitative estimate of tissue perfusion was then calculated from the maximum amplitude of \( h(t) \), scaled by the inverse of the sampling rate of the perfusion images. The region of interest drawn in the main pulmonary artery provided the arterial input function, and the region of interest drawn in the lung tissue represented the measured tissue enhancement. An initial low dose of gadolinium was used to estimate the lung perfusion, and subsequently a higher dose was used to produce a perfusion map based on changes in pixel-wise signal intensity. This sophisticated and innovative analysis provides quantification of total and regional lung perfusion.

Cao et al assessed pulmonary blood flow in 3 coronal slices using a 2-dimensional (2D) image acquisition. There are differences between this 2D technique and newer techniques using 3D image acquisition in spatial resolution,9,10 imaging time, and the dose of contrast required. Compared with 3D, with 2D imaging, less gadolinium is required, and image acquisition is faster (480 ms to image 3 lung slices versus 1.5 seconds to acquire a 3D data set) at the expense of lower spatial resolution (3 slices measuring 15 mm each versus 44 slices of the lung measuring 4 mm each). Although better spatial resolution would help assess inhomogeneity of lung perfusion at the segmental level, the current technique has produced comparable results to 3D acquisition and provides adequate resolution to assess perfusion at the lobar level.9,11 The faster imaging time and lower gadolinium requirement are especially important if sick patients are to be studied.

In the absence of an intracardiac shunt, the entire cardiac output flows through the lungs. Thus, it is reassuring that Cao et al2 found that the perfusion of the lungs is directly related to the cardiac output. More importantly, they examined the relative perfusion of lungs in the supine position. In normals,
there was a substantially greater perfusion of the dependent portions (ie, posterior) than the least dependent portion (anterior). Presumably, this reflects the additional hydrostatic pressure in the dependent portions of the lung. With HF, this gravitational gradient was blunted, being reduced in proportion to the left ventricular end-diastolic pressure. Thus, in HF, the perfusion to the dependent regions of the lung was reduced more than the flow to the anterior regions. In a multivariate analysis, this altered perfusion was most closely associated with elevated mean pulmonary artery pressure. This suggests that the redistribution against the hydrostatic gradient was because of pulmonary vasoconstriction that was more marked in the dependent portions of the lungs. Thus, there was a redistribution of flow to the less dependent portions of the lung. A similar cephalad redistribution of pulmonary flow seen on an upright chest x-ray is a classic finding of HF.

Dyspnea in HF is worse after lying down (orthopnea). It is likely that the redistribution of flow in the supine position, so elegantly described by Cao et al, contributes to orthopnea. In addition, in HF, an expansion and central redistribution of blood volume from the periphery with prolonged time in the supine position results in paroxysmal nocturnal dyspnea and contributes to central sleep apnea. In this regard, studies using the technique of Cao et al comparing the gravitational distribution of flow after a prolonged period in the supine position will also be valuable. There may also be shifts in the distribution of blood volume and alteration of the distribution of pulmonary perfusion during exercise. As such, studies of the effect of exercise would also be valuable.

Because pulmonary vasoconstriction seems to play an important role in producing the redistribution of lung perfusion in patients with HF, the technique of Cao et al may provide a powerful tool to assess the mechanism of benefit of the pulmonary vasodilator, sildenafil, in patients with HF with both reduced and preserved ejection fractions.2,11,14

In summary, many of the clinical manifestations of HF result from the impact on the lung. The new study of Cao et al points to the ability of innovative magnetic resonance techniques to provide new insight into the mechanisms of the heart’s impact on the lungs.

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References

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