Objectives: To develop and evaluate a postprocessing tool to quantify ventilated split-lung volumes on the basis of 3He-MRI and to apply it in patients after single-lung transplantation (SLTX). High-resolution CT (HRCT) was employed as a reference modality providing split air-filled lung volumes. Lung volumes derived from pulmonary function test results served as clinical parameters and were used as the “gold standard.”

Material and methods: Eight patients (mean age, 54 years) with emphysema and six patients (mean age, 58 years) with idiopathic pulmonary fibrosis. All patients were evaluated following SLTX. HRCT was performed during inspiration (slice thickness, 1 mm; increment, 10 mm). For correlation with 3He-MRI, HRCT images were reconstructed in coronal orientation to match the same anatomic levels. Aerated lung was determined by threshold-based segmentation of CT. 3He-MRI was performed on a 1.5-T scanner using a two-dimensional, fast low-angle shot sequence in coronal orientation covering the whole lung after inhalation of a 300-mL bolus of hyperpolarized 3He gas followed by normal room air for the rest of the tidal volume. Lung segmentation on 3He-MRI was done using different thresholds.

Results: In emphysematous patients, 3He-MRI showed excellent correlation (r = 0.9) with vital capacity, while CT correlated (r = 0.8) with total lung capacity. 3He-MRI correlated well with CT (r > 0.8) for grafts and native fibrotic lungs. In emphysematous lungs, MRI showed a good correlation (r = 0.7) with the nonemphysematous lung volume from CT. Increasing thresholds in 3He-MRI reveal differences between aerated and ventilated lung areas with a different distribution in emphysema and fibrosis.

Conclusions: 3He-MRI is superior to CT in emphysema to demonstrate ventilated lung areas that participate in gas exchange. In fibrosis, 3He-MRI and CT have a similar impact. The decrease pattern and the intraindividual ratio between ventilation of native and transplanted lungs will have to be investigated as a new surrogate for the ventilatory follow-up in patients undergoing SLTX.

Key words: CT; hyperpolarized 3He; MRI; single-lung transplantation; split-lung function

Abbreviations: au = arbitrary units; HU = Hounsfield units; HRCT = high-resolution CT; IPF = idiopathic pulmonary fibrosis; MLD = mean lung density; PFT = pulmonary function testing; SLTX = single-lung transplantation; SNR = signal-to-noise ratio; TLC = total lung capacity; VC = vital capacity

Lung transplantation is the ultimate treatment for patients with end-stage lung diseases such as cystic fibrosis, pulmonary hypertension, emphysema, and idiopathic pulmonary fibrosis (IPF). In the latter two diseases, transplantation of a single lung is generally regarded as sufficient, especially given the disbalance between candidates and grafts available.1,2 After single-lung transplantation (SLTX), patients have one healthy lung and one native, diseased lung.

After SLTX, patients are closely followed up by

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pulmonary function testing (PFT), which includes spirometry and body plethysmography. As a screening method, monitoring of FEV₁ and FVC are reproducible, but neither very sensitive nor specific. FEV₁ deterioration may be the result of a variety of posttransplant problems, such as rejection, pneumonia, bronchitis, disease progression, or hyperinflation of the native lung. PFT results only reflect the sum of native and transplanted lung. However, after SLTX it might be important to determine the individual contribution and compensation mechanism of each lung, referred to as split-lung function, by a noninvasive and sensitive diagnostic tool.

In suspected rejection or infection, high-resolution CT (HRCT) is the radiologic modality of choice for evaluation of lung structure and morphologic changes. As HRCT reveals anatomic information, morphologic changes are assigned to particular lobes and segments. Although CT is quite sensitive in the detection of changes, it is not very good at their differentiation. Therefore, invasive procedures, such as bronchoscopy with BAL and biopsy, are used to solve this diagnostic dilemma. With regard to functional analysis by CT, the impairment can only be estimated by assessment of the extent of the morphologic changes. However, there are—to our knowledge—no studies that demonstrate any correlation between the degree of functional impairment and the extent of morphologic changes in the SLTX setting.

At CT, lung volumes of patients undergoing SLTX can be calculated by use of density-based segmentation. Volumetric evaluations can also be done for each lung separately to provide split-lung volumes. The result reflects air-filled lung that corresponds to total lung capacity (TLC) as determined by PFT results. As this is a static volume acquired at maximum inspiration, it is only of limited value for functional evaluation. More important will be the determination of the ventilated lung volume that really contributes to gas exchange.

For direct visualization of ventilation, scintigraphy and single-photon emission CT can be used. Assessment of split-lung function has been performed in patients undergoing SLTX and improved the diagnosis of rejection. However, spatial resolution of lung scintigraphy is not sufficient for accurate assessment of regional lung volumes. Recently, a new method to image the lung was developed. By use of hyperpolarized ³He, it became possible to visualize ventilated airspaces by MRI. For imaging ³He using MRI, the scanner has to be adjusted to the appropriate resonance frequency (Larmor frequency) of ³He. Thus, selective visualization of ³He gas and its distribution within ventilated lung is achieved as no other structures give a signal. The data can be used for volumetric evaluation of ventilated lung reflecting vital capacity (VC). The objectives of this study were to develop and evaluate a postprocessing tool to quantify ventilated split-lung volumes on the basis of ³He-MRI and to apply it in patients after SLTX. HRCT was employed as a reference modality since it allows for split-lung analysis of air-filled lung volume. Lung volumes derived from PFT results served as established clinical parameters and were used as the “gold standard.”

**Materials and Methods**

We examined eight male patients (mean age, 54 ± 6 years [± SD]; range, 45 to 62 years) with emphysema and six patients (three men and three women; mean age, 58 ± 9.5 years; range, 47 to 71 years) with IPF. All patients were evaluated following SLTX. Patients with emphysema were evaluated 678 ± 795 days after transplantation, and patients with fibrosis were evaluated 717 ± 415 days after transplantation. During examinations, there was neither evidence nor suspicion of bronchiolitis obliterans. The body mass indexes of our study population were 23.7 ± 2.5 in patients with emphysema and 26.7 ± 3 in patients with fibrosis. Patients were categorized into two groups according to their disease and evaluated separately.

All subjects underwent PFT performed according to the Guidelines of the European Respiratory Society. The following volume measurements were chosen for correlation with radiologic methods: TLC and VC. ³He-MRI and PFT were performed the same day. HRCT was performed within 7 days.

HRCT was performed using a Siemens Somatom 4 Plus scanner (Siemens Medical Systems; Erlangen, Germany) as part of standard clinical follow-up. CT was done during an inspiratory breath-hold in supine position. Slice thickness was 1 mm, and increment was 10 mm, resulting in 26 to 28 slices covering the whole lung. A high-frequency reconstruction algorithm was used. For assessment of mean lung density (MLD), three axial slices (level of carina, 3 cm above, 5 cm below) were evaluated using the Pulmo-Software implemented on the scanner (Siemens Medical Systems). After semiautomatic segmentation of the lung, MLD was calculated for each lung separately.

With approval of the local ethics committee and after written informed consent, ³He-MRI studies were performed on a 1.5 T Magnetom Vision (Siemens Medical Systems). A certified transmit/receive coil (Fraunhofer Institute; St. Ingbert, Germany) operating at the Larmor frequency of ³He (48.4 MHz) was manually tuned and matched for each patient. A two-dimensional, fast low-angle shot sequence was applied in coronal orientation with a repetition time of 11 ms and an echo time of 4.2 ms. Total receiver gain was 55 decibels, and transmitter amplitude was 30 V, corresponding to a flip angle between 6° and 10°. The acquisition matrix size was 81 × 128, and the field of view was 320 mm. Before image reconstruction, the raw data were zero filled to a 256 × 256 matrix. Slice thickness was 10 mm, with a 5-mm interslice gap. In-plane spatial resolution was 4.0 × 2.5 mm; 14 coronal slices were obtained to cover the whole lung. The breath-holding period was 13 s. During the investigation, blood oxygenation and heart rate were monitored continuously by pulse oximetry.

The technical prerequisites and production of hyperpolarized ³He gas used at our institution have already been reported.
ma.26,27 The emphysematous lung volumes were regarded as the rest of tidal volume. The whole examination lasted for 300 mL of the gas were inhaled, followed by normal room air for respiration in predefined gas quantities using a personal computer-controlled gas delivery device. At the beginning of inspiration, 300 mL of the gas were inhaled, followed by normal room air for the rest of tidal volume. The whole examination lasted for < 45 min, and often it was performed within half an hour.

Image Analysis

All images were transferred to a separate workstation (Magic View; Siemens Medical Systems), and MRI and HRCT images were displayed simultaneously on the dual monitor. Scrolling through the stack of MRIs, we identified anatomic landmarks such as trachea, carina, or main bronchi. Coronal CT was reconstructed using interactive multiplanar reformations with the same landmarks to generate a matching slice. This slice served as the starting point for all other coronal reformats using the same fixed parameters as in MRI (10-mm slice thickness and 5-mm gap). Thus, 14 CT slices were generated in coronal orientation.

On all CT slices, both lungs were outlined separately using a double-threshold technique – 1,024/– 200 Hounsfield units (HU) to give the volume of air-filled lung that was correlated with TLC.10 In patients with emphysema, we additionally used – 1,024/– 950 HU to determine the volume of the emphysema.26,27 The emphysematous lung volumes were regarded as functionally inactive and not participating in gas exchange (“closed volume”). By subtraction of the emphysematous volume from the whole air-filled lung volume, we obtained the nonemphysematous lung volume.

To validate the lung density measurements, MLD of the 14 coronal reformats was compared to MLD measured on the three transaxial slices. We found a high correlation (r = 0.99) with a systematic underestimation of 7%. This enabled us to use the measurements on the coronal reformats for comparison with 3He-MRI (Fig 1).

For lung segmentation, 3He-MRI images and coronal CT reformats were displayed at the same anatomic level side by side. We outlined the lung borders on the CT and then transferred them to the corresponding MRI slice. This procedure was necessary to determine the total lung volume on 3He-MRI images, as there are no anatomic landmarks visible but ventilated lung.

Volumetric evaluation of the ventilated lung at 3He-MRI was performed with a double-threshold technique. First, a region of interest was drawn outside the lung to measure mean signal intensity (mean noise) and SD (SD noise) of background noise in each slice. For lung volume segmentation, the upper threshold was set to the maximum signal intensity (4,095 arbitrary units [au]), and the lower threshold was set to mean noise plus 2 SD noise.20

Since the lung volume containing the 3He gas corresponds to the ventilated volume, calculated volumes from 3He-MRI were correlated with VC from PFT. Besides comparison of the radiologic results with PFT, both radiologic modalities were compared with each other for graft and native lung separately.

To elucidate intrapatient differences in the distribution of ventilation between native and graft lung further, five different thresholds were used as lower thresholds: – 2,000 (base volume), mean noise, mean noise plus 1 SD noise, mean noise plus 2 SD noise, and mean noise plus 3 SD noise. The whole individual lung volume was taken as starting point (ie, 100%).

Results

Emphysema

The mean TLC from PFT results in patients with emphysema was 6,359 ± 757 mL (95 ± 11% predicted), and mean VC was 3,336 ± 479 mL (73 ± 13% predicted). Mean air-filled lung volume from CT was 7,098 ± 1,533 mL, and nonemphysematous volume was 5,407 ± 767 mL. Mean segmented lung volume from 3He-MRI (−2,000/4,095 au) was 7,680 ± 1,856 mL, and the mean ventilated lung volume (mean noise plus 2 SD noise/4,095 au) was 3,761 ± 854 mL.

Correlation between TLC and air-filled lung volume derived from CT showed a high correlation (r = 0.8). VC showed even higher correlation (r = 0.9) with ventilated lung volume derived from 3He-MRI (Fig 2).

For the grafted lung, a high correlation (r = 0.7) between the ventilated lung volume from 3He-MRI and the air-filled lung volume from CT was found. The nonemphysematous volume in CT led to an even higher correlation (r = 0.8; Fig 3, top, A).

For the native lung, no meaningful correlation (r = 0.5) between the ventilated lung volume from 3He-MRI and the air-filled lung volume from CT was found. Looking at the nonemphysematous lung volume from CT, a good correlation (r = 0.7) between both modalities (Fig 3, bottom, B) was found. At the same time, there was a high correlation (r = 0.9) between the nonventilated lung volume at 3He-MRI ([base volume – 2,000 au] – ventilated volume [mean plus 2 SD]) and emphysematous volume calculated from CT.

At 3He-MRI, the grafted lung contributed 72 ± 14% to total ventilated lung volume, whereas
the native lung contributed only 28 ± 14%. At CT, the ratio of air-filled lung was 44 ± 8% to 56 ± 8%. Looking at the nonemphysematous data at CT, the graft contributed 54 ± 4% to total lung volume, and the contribution of the native lung was 46 ± 4%.

**IPF**

The mean TLC in patients with IPF was 3,823 ± 1,063 mL (73 ± 18% predicted), and mean VC was 2,647 ± 818 mL (71 ± 16% predicted). Mean air-filled lung volume from CT was 3,443 ± 814 mL. Mean segmented lung volume from ⁴He-MRI (−2,000/4,095 au) was 3,869 ± 1,127 mL, and the mean ventilated lung volume (mean noise plus 2 SD noise/4,095 au) was 3,502 ± 868 mL.

Correlation between TLC and air-filled lung volume derived from CT showed a high correlation (r = 0.9). VC showed an extremely high correlation (r = 0.96) with ventilated lung volume derived from ⁴He-MRI (Fig 4). There was excellent correlation (r = 0.9) of ventilated lung volumes from ⁴He-MRI with the air-filled lung volume from CT for transplanted and native lungs.

At ⁴He-MRI, the graft contributed 64 ± 6% to total lung volume, whereas the native fibrotic lung contributed only 36 ± 6%. At CT, the ratio was very similar: 67 ± 5% to 33 ± 5%.

**³He-MRI: Emphysema vs IPF**

The whole individual lung volume was taken as the starting point (ie, 100%). A stepwise increase of the lower threshold demonstrated a marked discrepancy between the emphysematous and transplanted lung (Fig 5, top, A). The transplanted lung decreased to 76 ± 10 (mean noise plus 3 SD noise), whereas the native emphysematous lung decreased to 17 ± 11%. The difference between graft and emphysematous lung was 59%.

In fibrotic patients, there was only a small decrease of segmented area (Fig 5, bottom, B). The transplanted lung decreased to 95 ± 4% (mean noise plus 3 SD noise), whereas the native fibrotic lung decreased to 81 ± 11%. The difference between graft and fibrotic lung was only 14%.

**FIGURE 2.** The different volumes determined in patients after SLTX due to emphysema, with a better result for ⁴He-MRI. Top, A: Correlation between air-filled lung volume from CT and TLC from PFT. Bottom, B: Correlation between ventilated lung volume from ⁴He-MRI and VC from PFT.

**FIGURE 3.** Correlation between nonemphysematous (non-empth.) lung volume from CT and ventilated lung volume from ³He-MRI for grafted (top, A) and native (bottom, B) lungs in patients after SLTX due to emphysema.
In this study, the value of HRCT and $^3$He-MRI for functional quantification of different lung volumes in patients after SLTX was assessed. Lung volumes determined by CT using a standard threshold method correlate with TLC and represent air-filled lung. Lung volumes determined by $^3$He-MRI using a double-threshold technique correlate with VC and represent ventilated lung. Both methods allow for direct assessment of split-lung volumes. In patients with emphysema, the emphysematous parts of the lung do not participate in gas exchange. In patients with IPF, air-filled (CT) and ventilated lung (MRI) are substituted by tissue in the same way. Therefore, volumetric results based on CT and MRI are similar.

Lung transplantation has evolved during the past 2 decades to become a viable option for end-stage pulmonary disease. Especially SLTX is the most commonly used technique for nonseptic lung disease. Although PFT is considered the "gold standard" for lung function testing, it shows a considerable degree of variability and is highly patient dependent. Furthermore, the value of routine daily spirometry in stable SLTX patients has not been established. Several factors may obscure the accuracy of spirometry in this patient population. The remaining native lung generates volumes and flow rates that will be averaged with the ones of the allograft. In addition, the native lung may experience exacerbation or progression of the underlying disease, further decreasing the specificity of spirometry in detecting pathology within the graft.

CT and $^3$He-MRI are capable of split-lung analysis. An important advantage of $^3$He-MRI is the lack of radiation exposure, which is even more appreciated for repetitive studies.

**DISCUSSION**

In this study, the value of HRCT and $^3$He-MRI for functional quantification of different lung volumes in patients after SLTX was assessed. Lung volumes determined by CT using a standard threshold method correlate with TLC and represent air-filled lung. Lung volumes determined by $^3$He-MRI using a double-threshold technique correlate with VC and represent ventilated lung. Both methods allow for direct assessment of split-lung volumes. In patients with emphysema, the emphysematous parts of the lung do not participate in gas exchange. In patients with IPF, air-filled (CT) and ventilated lung (MRI) are substituted by tissue in the same way. Therefore, volumetric results based on CT and MRI are similar.

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CT and $^3$He-MRI are capable of split-lung analysis. An important advantage of $^3$He-MRI is the lack of radiation exposure, which is even more appreciated for repetitive studies.

**CT**

For visualization of morphologic changes, HRCT is the modality of choice. Using HRCT function can only be estimated from assessment of the extent of the morphologic changes. Quantitative data derived from CT, using either spiral or high-resolution techniques, are MLD and percentages of area below
defined thresholds. Several studies\textsuperscript{26,27} have proven that for quantification of emphysema on HRCT the thresholds $-950$ to $-1024$ HU should be used. Quantitative data derived from repeated spiral CT showed excellent correlation between both measurements.\textsuperscript{29} The two scans were performed in inspiratory breath-holding in free-breathing patients and showed that patient collaboration is easy to achieve for an inspiratory breath-hold. As there are no data in the literature about quantitative measurements on coronal reformats of HRCT, we demonstrated the accuracy of both measurements.

The calculated volumes for both lungs from inspiratory CT were compared with TLC and showed a high correlation, which is in the range of data previously published.\textsuperscript{10,12,13} These results demonstrate that inspiratory CT measures air-filled lung volume. However, for further assessment it is important to determine the ventilated lung volume that contributes to gas exchange.

$\textsuperscript{3}$He-MRI

Previous studies\textsuperscript{20,30} showed that volumetry of lungs filled with $\textsuperscript{3}$He-gas is possible and results correlate with PFT. Ventilated lung volume was determined by applying a lower threshold for segmentation of mean noise plus 2 SD noise for the lung segmentation.\textsuperscript{20} The same threshold was used for split-lung evaluation. To test if our results also correlate with PFT data, we added the two split-lung volumes, and found a very high correlation with VC for both patient groups. Therefore, $\textsuperscript{3}$He-MRI represents the parts of the lung that actively participate in

Figure 6. Segmentation of $\textsuperscript{3}$He-MRI and CT in a male patient (50 years old) after SLTX on the left due to emphysema. Top left, a: $\textsuperscript{3}$He-MRI with the lungs outlined. Borders are based on the real lung borders as seen on the CT image reconstructed at the same anatomic level. Top right, b: Segmented area with the lower segmentation threshold set to mean plus 2 SD. These parts are filled with $\textsuperscript{3}$He and can be called ventilated lung. Bottom left, c: Coronal reconstructed HRCT matching the same anatomic level as the corresponding $\textsuperscript{3}$He-MR image (top left, a). Bottom right, d: Emphysematous regions (lower threshold, $-1,024$ HU; upper threshold, $950$ HU) segmented. The emphysematous parts are located in the right lower lobe corresponding to the nonventilated parts at $\textsuperscript{3}$He-MRI (top right, b).
ventilation and thus gas exchange in patients with emphysema or fibrosis.

**CT vs ³He-MRI**

Volumetric comparison between lung volumes derived from CT and ³He-MRI for the transplanted lungs in both patient groups showed a high correlation. This demonstrates that normal lung parenchyma can be volumetrically assessed by CT and ³He-MRI in a similar fashion.

In emphysematous lungs, there was no correlation between the two measurements using a simple quantification approach. By restricting the comparison to the nonemphysematous part of the total air-filled volume determined at CT, the correlation markedly improved. These results indicate that the emphysematous areas receive no ³He during inspiration and are not ventilated in a single-breath investigation. This is also obvious on the images (Fig 6) where the emphysematous areas segmented at CT contained very little or no ³He-gas at MRI. To use CT for functional quantification in emphysema, the emphysematous areas have to be subtracted rigorously.

In fibrotic lungs, a high correlation between the lung volumes derived from ³He-MRI and CT was found. This is shown on Figure 7, where the fibrotic lesions on CT were seen as ventilation defects at MRI. Thus, in patients with IPF, CT is similar to ³He-MRI.

**Decrease Pattern**

Looking at the decrease of ventilated area after increasing the lower threshold used for segmentation, a marked difference was found between emphysematous and fibrotic lungs. The emphysematous lungs were hyperinflated and had an inhomogeneous ventilation distribution, with large parts only sparsely filled with ³He gas as can be concluded from the steep decrease of the segmented area down to 17% while increasing the lower threshold. The fibrotic lungs were smaller, and thus the remaining lung parenchyma was well ventilated as indicated by the slight decrease of segmented area down to 81%.

However, there was also a difference for the transplanted lungs between both patient populations. In patients with IPF, the transplanted lung decreased only by 5%, while it decreased by 24% in patients with emphysema. Two reasons might cause lower values in emphysema: (1) hyperinflation or emphysema within the transplant, or (2) dilution of ³He-gas within a larger tidal volume resulting in a lower signal-to-noise ratio (SNR). The first explanation is unlikely, as emphysema, in contrast to other disease, does not recur within the transplant. Simple hyperinflation due to the large thoracic cavity is also unlikely as CT attenuation of the transplanted lungs did not differ between both groups.

The tidal volume of the emphysema patients at the time of the MRI examination was nearly twice as high (1,300 mL) as in patients with IPF (700 mL). Nevertheless, both patient groups received the same standard dose of ³He-gas (300 mL). After dilution, the effective dose of ³He-gas was significantly smaller in emphysema patients, resulting in a lower SNR, which explains the different decrease patterns for the transplanted lungs. The intraindividual ratio between ventilation of native and transplanted lungs, however, is not affected by differences in SNR. Thus, this kind of analysis should be investigated further in the follow-up of SLTX patients.

We acknowledge some limitations of our study.

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**Figure 7.** Segmentation of ³He-MRI and coronal reconstructed CT in a male patient (71 years old) after SLTX on the left due to IPF. Left, a: Segmentation of the lung in a ³He-MR image with the contours taken from the CT image. The fibrotic changes are seen as ventilation defects. Right, b: Coronal reconstructed HRCT.
The population only consisted of patients with endstage disease. Therefore, the results have to be confirmed in patients with less parenchymal destruction. Furthermore, the study population was quite small and the results cannot be transferred to a larger population without further investigations. However, polarized $^3$He-gas is not commercially available since polarization of the $^3$He-gas and $^3$He-MRI are only performed in dedicated centers. $^3$He-gas is not approved by the US Food and Drug Administration, but phase II clinical trials are ongoing. Dedicated polarizers might become commercially available in the future. Nonpolarized $^3$He-gas is rather expensive, as 1 L costs approximately $100 (US dollars)$^{32}$; polarized gas will be even more expensive. However, given the costs of lung transplantation with medication charges alone frequently exceeding $1,000 dollars per month,$^1$ $^3$He-MRI might be cost-effective if early detection of bronchiolitis obliterans can be proven.

In summary, we found that lung volumes determined by CT represent air-filled lung while lung volumes determined by $^3$He-MRI represent ventilated lung. Thus, $^3$He-MRI is superior to CT in emphysema, selectively demonstrating ventilated lung areas that participate in gas exchange. Large air-filled areas that are detected by CT are not ventilated and do not contribute to gas exchange ("closed volume"). In fibrosis, $^3$He-MRI and CT have a similar impact since ventilation defects are caused by an increase in tissue. The decrease pattern and the intranidividual ratio between ventilation of native and transplanted lungs will be investigated further in longitudinal follow-up studies of patients undergoing SLTX.

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REFERENCES

1 Trulock EP. Lung transplantation. Am J Respir Crit Care Med 1997; 155:789–815