Clinical evaluation of $^{99m}$Tc-Technegas SPECT in thoracoscopic lung volume reduction surgery in patients with pulmonary emphysema

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$^{99m}$Tc-Technegas (Tegas) SPECT is useful for evaluating the patency of the airway and highly sensitive in detecting regional pulmonary function in pulmonary emphysema. The aim of this study is to evaluate regional ventilation impairment by this method pre and post thoracoscopic lung volume reduction surgery (LVRS) in patients with pulmonary emphysema. Methods: There were 11 patients with pulmonary emphysema. The mean age of patients was 64.1 years. All patients were males. LVRS was performed bilaterally in 8 patients and unilaterally in 3 patients. Post inhalation of Tegas in the sitting position, the subjects were placed in the supine position and SPECT was performed. Distribution of Tegas on axial images was classified into 4 types, A: homogeneous, B: inhomogeneous, C: hot spot, D: defect. Three slices of axial SPECT images, the upper, middle and lower fields were selected, and changes in deposition patterns post LVRS were scored (Tegas score). Results: Post LVRS, dyspnea on exertion and pulmonary function tests were improved. Pre LVRS, inhomogeneous distribution, hot spots and defects were observed in all patients. Post LVRS, improvement in distribution was obtained not only in the surgical field and other fields, but also in the contralateral lung of unilaterally operated patients. In 5 patients some fields showed deterioration. The Tegas score correlated with improvements in FEV$_{1.0}$, FEV$_{1.0}$$\%$ and $\%$FEV$_{1.0}$. Conclusion: Tegas SPECT is useful for evaluating changes in regional pulmonary function post LVRS.

Key words: $^{99m}$Tc-Technegas, SPECT, pulmonary emphysema, lung volume reduction surgery, thoracoscopic surgery

INTRODUCTION

Volume reduction surgery (LVRS) has recently been indicated for pulmonary emphysema, which was previously treated only with conservative therapy with medication. Since about 1990, a number of studies have reported that thoracoscopic volume reduction surgery relieves symptoms and improve pulmonary function. Postoperative pulmonary function is often evaluated by pulmonary function tests, but these tests reveal whole pulmonary function, and so examination with radioisotopes is most suitable for the evaluation of regional pulmonary function. Tc-99m-Technegas (Tegas) (carbon microparticles labeled with Tc-99m) can be used for imaging of regional pulmonary ventilation on the basis of its alveolar deposition post inhalation. Three-dimensional Tegas imaging with SPECT is also available. To evaluate the usefulness of Tegas, regional pulmonary function was investigated with Tegas inhalation SPECT performed pre and post thoracoscopic LVRS in patients with pulmonary emphysema.

This study was designed to evaluate the usefulness of Tegas for LVRS in 11 patients with pulmonary emphysema. Before the study, the nature of the study was fully explained to the patients and their informed consent was properly obtained.
### Table 1  Clinical symptom and pulmonary function tests pre and post LVRS

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (F-H-J)</th>
<th>DOE</th>
<th>Pulmonary Function Tests</th>
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<td>11</td>
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<td>4</td>
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</table>

Mean 64.1 **3.5** *2.1* 68.9 *75.2 73.4 74.2 884 *1191 36.2 48.1 31.5 43.0

SD 5.1 0.5 0.8 9.9 7.3 19.2 14.3 488 547 8.7 17.1 18.8 21.2

DOE = Dyspnea on exertion, F-H-J = Frecher-Hugh-Jones classification, Pre = Pre LVRS, Post = Post LVRS, ⊗= Oxygen inhalation case, ** = p < 0.01, * = p < 0.05

## SUBJECTS AND METHODS

The subjects consisted of 11 male patients with pulmonary emphysema aged between 54 and 73 years (mean, 64.1 years). Six cases out of 11 had bulla. LVRS was performed in all patients; bilateral surgery in 8 and unilateral surgery in 3 (cases Nos. 9 and 10: left lung, case No. 11: right lung). Bullectomy was performed in 6 patients and pneumectomy and laser ablation in all patients (Table 1).

### Preparation and Inhalation of Tegas

Tegas consisting of microparticles with a diameter of 5 nm was produced in a Tegas generator (Tetley Technologies) filled with argon gas, where sodium pertechnetate in normal saline was inserted into a graphite crucible and heated to 2500°C. Patients sitting with a nose clip on were instructed to inhale Tegas several times through a 1-liter tube from functional residual capacity (FRC) to total lung capacity (TLC). To obtain an adequate pulmonary deposition of Tegas, patients were also instructed to stop breathing for about 3–5 seconds at the TLC level. Post inhalation of Tegas at a level of about 200,000 counts/min, SPECT was performed in the supine position. The gamma camera used was MULTISPECT3 (Siemens) with parallel-type, low-energy, high-resolution collimators. SPECT images obtained with a matrix size of 128 by 128, step angle of 4°, acquisition time of 40 sec and 90 acquisition directions were synthesized without attenuation correction to reconstruct 3 slices which were then combined into one axial image (10.5 mm in total).

### Case Presentation

#### Case no. 4

A 66-year-old male was treated with bilateral bullectomy and pneumectomy.

The patient had exertional dyspnea, severe obstructive ventilatory disturbance of a obstructive disorder and hypoxemia. With CT and Tegas findings bilateral lower lung lobes were targeted for volume reduction (Fig. 1aA, 1bA). LVRS was performed as video-assisted thoracoscopic surgery (VATS). Surgical reduction of lung volume (the left lung from the base to S6 and the right lung from S6 to S9) was achieved uniformly through serial nonsegmental wedge resection with a 45 mm thoracoscopic linear cutter. After resection by stapler, emphysematous tissue was laser-ablated. Post LVRS, CT showed the expansion of compressed residual lung lobes and distribution of Tegas improved remarkably. In dorsal bilateral lower lung lobes, CT identified normal lung structure, but Tegas showed defects indicating ventilation disorder (Fig. 1aB, 1bB). The degree of dyspnea, pulmonary function and PaO₂ improved.

#### Case no. 11

A 65-year-old male was treated with right pneumectomy.

The patient had severe exertional dyspnea and mixed ventilatory disturbance of restrictive and obstructive disorders. Plain chest X-ray showed hyperlucent bilateral lung fields especially in the bilateral lower fields. CT images showed low attenuation areas, especially in the upper and lower lung fields. Nevertheless, Tegas SPECT showed severe inhomogeneity with hot spots and defects particularly in the right lung (Fig. 2aA, 2b, 2cA). LVRS was performed on the right lung (S2 to the apex, middle lobe and base). After resection by stapler, emphysematous tissue was laser-ablated. Post LVRS, chest X-ray showed decreases in volume and radiolucency of the right lung. Tegas images homogeneity improved not only in the surgical lung but also in the contralateral lung (Fig. 2aB, 2cB). The degree of dyspnea and pulmonary function improved.
Scoring of Pulmonary Tegas Distribution
A scoring method was developed to compare pre and post LVRS distributions of Tegas in axial SPECT images. Three slices were chosen for this purpose: an upper slice at the middle of the trachea, a middle slice just below the carina and a lower slice equidistant between the carina and base. Tegas distribution in each slice was classified into 4 types according to our simplified classification for pulmonary Tegas planar images. Postoperative improvement of 1 type (e.g. from type C to type B) was scored +2 points. Deterioration of 1 type was scored -2 points. A slight improvement (e.g. reduction of inhomogeneity in type B was named type B+, reduction of hot spots in type C was named type C+, reduction of defects area in type D was named type D+) was scored +1 point. A slight deterioration (e.g. increase of inhomogeneity in type B named type B–, increase of hot spots in type C was named type C–, increase in defects area in type D was named type D–) was scored -1 point (Fig. 3).

RESULTS
Tegas Deposition Patterns and Tegas Scores
Pre LVRS, inhomogeneous distribution and hot spots were observed and the proportion of types C and D deposition patterns was high. Post LVRS, distribution of Tegas showed improvement or no change in any slice in 6 of 11 patients and deterioration was not observed. But in 5 patients deposition patterns were partially deteriorated (Table 2). The Tegas score for whole lung and bilateral lungs improved in all patients. Tegas distribution and Tegas scores in the contralateral lung improved postoperatively in all 3 patients who underwent unilateral LVRS (Fig. 4).

Changes in Pulmonary Function Tests Post LVRS
Pulmonary function tests pre surgery showed severe obstructive or mixed ventilatory impairment in all patients. Clinical symptoms evaluated by the F-H-J classification improved in 10 patients (90.9%) but showed no change in one patient (9.1%). In 9 patients who underwent blood gas analysis without the assistance of oxygen therapy, PaO₂ improved in 8 patients (89%). As for other variables,
Fig. 2
a. Pre LVRS, plain chest X-ray showed overinflation and hyperlucent bilateral lung fields especially in the lower fields (A). Post LVRS, chest X-ray showed decreases in volume and radiolucency of the right middle lower lung field (B).
b. Pre LVRS, entire bilateral lungs CT images showed low attenuation areas, especially in the upper and lower lung fields.
c. Pre LVRS, Tegas SPECT axial images showed severe inhomogeneity with hot spots and defects particularly in the right lung (A, lower to upper slices). Post LVRS, Tegas distribution was improved. Homogeneity improved in the contralateral lung (B).

Fig. 3 Scoring of pulmonary Tegas distribution. The degree of inhomogeneous distribution was classified into 4 types (A–D). Type A: homogeneous (normal distribution as healthy control), type B: inhomogeneous (inhomogeneous distribution without hot spot and defect), type C: hot spot (inhomogeneous distribution with hot spots), type D: defect (inhomogeneous distribution with defect). And postoperative improvement were evaluated by this classifications.

%VC improved in 8 (72.7%), FEV_{1.0} in 10 (90.9%), FEV_{1.0}% in 9 (81.8%) and %FEV_{1.0} in 10 (90.9%) of 11 patients. Significant differences were found between preoperative and postoperative values except in %VC (Table 1).

Fig. 4 In Tegas scores post LVRS, improved in all patients (100%). In unilateral LVRS patients (Case nos. 9, 10: left LVRS; case no. 11: right LVRS), the contralateral lung also showed improvement.

**Relationship between Tegas Score for Whole Lung and Percentage Improvement in Pulmonary Function Tests**
A correlation was found between the Tegas score and the percentage improvement in FEV_{1.0} (p < 0.01, R = 0.9), FEV_{1.0}% (p < 0.05, R = 0.78), and %FEV_{1.0} (p < 0.05, R = 0.8...
DISCUSSION

Tegas consisting of microparticles with a diameter of 5 nm is deposited in normal alveoli by inhalation and produces images very similar to ventilation images, but it behaves like an aerosol in that an unequal accumulation of microparticles occurs in patients with obstructive pulmonary disease resulting in "hot spots," an excessive deposition of isotopes in the airways. Thus Tegas does not produce accurate ventilation images in patients with

<table>
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<th>Case No.</th>
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</table>

*: Improved, -: Deterioration

**Table 2** Tegas deposition patterns pre and post LVRS

![Figure 5](image_url)

**Fig. 5** The relationship between Tegas score post LVRS and improvement percentage of pulmonary function tests can be seen in this figure. In each pulmonary function test, the higher the Tegas score was the higher the improvement percentage was. The correlation between Tegas score and improvement percentage of FEV₁₀, FEV₁₀%, %FEV₁₀ were statistically significant.
obstructive pulmonary disease,10-12 yet it can be used to
detect airway abnormalities in patients with obstructive
pulmonary disease. Findings in SPECT with Tegas corre-
spond well to findings in CT. It has been reported that
Tegas SPECT is more sensitive in detecting regional
pulmonary dysfunction than high resolution CT (HRCT)
in pulmonary emphysema.13 In the 2 cases presented,
Tegas SPECT images indeed revealed regional pulmon-
ary dysfunction more sensitively than HRCT.

Chronic pulmonary emphysema is an irreversible dis-
case characterized by alveolar destruction. The useful-
ness of surgery has recently been reevaluated for therapy
of pulmonary emphysema, which was conservatively
 treated in the past. Due to recent advances in thoraco-
scopy, not only bullectomy but also LVRS is more fre-
quently performed, and found to be effective in improving
pulmonary function.14-17 Thoracoscopic procedures re-
move emphysematous lesions and bullae which compress
normal lung tissue. Chest CT and pulmonary function
tests have been used to determine the extent of resection
and to evaluate postoperative results.18,19 It is possible to
evaluate pulmonary structure in detail in pulmonary em-
physema by HRCT, but HRCT images cannot reveal
pulmonary function. Pulmonary function tests reveal whole
pulmonary function, but they cannot reveal regional pul-
monary function, whereas nuclear imaging can. There-
fore nuclear imaging is useful for evaluating LVRS.

Previously the usefulness of ventilation perfusion imaging
with 133Xe gas or 99mTc-MAA has been reported,20,21
but only planar imaging is available in a usual 133Xe gas
ventilation study. Even if dynamic SPECT were used, 3-
dimensional ventilation imaging could not be obtained.
Perfusion studies are used for evaluating LVRS. But
ventilation is important for evaluating pulmonary func-
tion. Ventilation defects lead to secondary changes in
perfusion in chronic airway diseases. Moreover perfusion
is underestimated in upper lung area because of gravity, so
it is difficult to locate a target area in pulmonary emphy-
sema with predominantly upper lung lesions. In this study,
we studied the usefulness of Tegas SPECT for 3-di-
ensional evaluation of pulmonary function post LVRS.
Severe obstructive ventilatory impairment was found in
most of our patients. Moreover, preoperative Tegas dis-
tribution in SPECT images showed marked inhomogeneity
and hot spots in all of our patients. We adopted the
semiquantitative method of scoring which has been used
in our institution for visual assessment of pulmonary
Tegas planar images. We previously reported that the
classification of Tegas planar image had a good correla-
tion with FEV1.0 and %FEV1.0, conventional indexes of
obstructive pulmonary function impairment, in patients
with various pulmonary diseases.11,12 The present study
confirmed that pulmonary distribution of Tegas improved
post LVRS in all patients. In those patients, pulmonary
function and clinical symptoms also improved post sur-
gery although the degree of improvement varied among
cases. Tegas distribution in the contralateral lung
improved postoperatively in all 3 patients who underwent
unilateral LVRS. It has been reported that the improve-
ment in pulmonary function post LVRS is attributable to
the improvement of lung elastic recoil. Recoil pressures
may act in the direction of airway dilatation.22 Thoracic
movements, including diaphragmatic movements, play
an important role in postoperative results. Improvement
in the operated lung might facilitate diaphragmatic move-
ments in the contralateral lung.23 On the other hand, some
pulmonary areas showed deterioration of Tegas distribu-
tion post surgery in some cases. It has been suggested that
regional deterioration of Tegas distribution might occur
even in cases where the overall pulmonary function im-
proved post surgery. A correlation was found between the
Tegas score for the whole lung and FEV1.0, FEV1.0%,
%FEV1.0. It has been reported that FEV1.0 is the best index
of pulmonary function improvement post LVRS.1,3

The present study suggested that the Tegas score was another
good index of pulmonary function. Three presented slices
were chosen in this study. Because lung size varies, the
number of slices also varies, making semiquantitative
evaluation impossible. SPECT images are more useful
than previously used planar images in evaluating 3-di-
ensional pulmonary function and in evaluating regional
pulmonary function in upper, middle and lower fields. In
the cases in this study, bilateral levels of the diaphragm
were almost the same pre and post LVRS, so there was
little influence as a result of the change in lung shape.
Tegas SPECT is expected to be useful for evaluating
regional pulmonary function and postoperative results in
patients with pulmonary emphysema.

CONCLUSION

Technegas inhalation SPECT is useful for evaluating
regional pulmonary function pre and post thoracoscopic
lung volume reduction surgery in patients with pulmon-
ary emphysema.

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