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The Complementary Roles of Chest Radiography, Lung Scanning, and Selective Pulmonary Angiography in the Diagnosis of Pulmonary Embolism

By David C. Moses, M.D., Terry M. Silver, M.D., and Joseph J. Bookstein, M.D.

SUMMARY
The chest X-ray, perfusion lung scan, and selective pulmonary arteriogram were independently reviewed in 104 patients with suspected pulmonary embolism. Thirteen patients also had 133Xe ventilation studies. Of the 45 patients with angiographically-documented pulmonary emboli, 37 had perfusion scans interpreted as high probability of pulmonary embolism (82% sensitivity). Fifty of 59 patients without angiographic evidence of pulmonary embolism had perfusion scans interpreted as low probability of pulmonary embolism, other, or normal (85% specificity).

Of the 41 patients with acute pulmonary embolism, only three had normal chest X-rays. In 26 (63%) the abnormality on perfusion scan was more extensive than that on chest X-ray.

When both the scan and chest X-ray pointed strongly in the same direction, a correct diagnosis could usually be made, and accuracy was greater than when diagnosis was based on the perfusion scan alone. The lung scan was of limited value in patients with cardiomegaly or left heart failure. The differential role of the 133Xe ventilation study remains unclear. On the basis of the present and other data, guidelines for the selection of patients for pulmonary arteriography are proposed.

Additional Indexing Words:
Radioisotope lung scan
Chest X-ray
Pulmonary arteriogram

In making the diagnosis of pulmonary embolism the clinician seeks to obtain diagnostic studies which are both sensitive and specific. Pulmonary perfusion imaging with radiolabelled particles is well accepted as a very sensitive but relatively nonspecific tool in the diagnosis of pulmonary embolism.1-5 The chest radiograph lacks both sensitivity and specificity.6,7 Pulmonary angiography with selective lobar and segmental injections is both highly sensitive and specific in the detection of pulmonary emboli, but it should not be used as a routine screening procedure. In an effort to arrive at guidelines for the most efficient utilization of these diagnostic procedures, we have evaluated perfusion scans and in some cases combined ventilation/perfusion studies in conjunction with chest X-rays in 104 patients who had high quality selective and subselective pulmonary angiography for suspected pulmonary embolism.

Methods and Patients
During the years 1968 through 1972 at the University of Michigan Medical Center perfusion lung scans were performed in 858 patients and pulmonary angiograms in 298 patients suspected of having pulmonary embolism on clinical grounds. Of these patients 116 had both perfusion scans and pulmonary angiograms which were available for review. Twelve patients were excluded because of technically unsatis-
factory studies or because too great a time interval had elapsed between the studies. The remaining 104 patients, each of whom also had a routine chest X-ray, form the basis of this report. Each of the diagnostic studies was reviewed separately and without knowledge of the interpretations of the others.

Perfusion lung scans were performed following the intravenous injection of 300 µCi of 131I macroaggregate-albumin in 67 patients, and 2 mCi of technetium-99m-albumin microspheres in 37 patients. Anterior, posterior, and both lateral views were obtained with a 5 inch dual probe rectilinear scanner in all except three patients who had images on a scintillation camera.

Thirteen patients also had xenon-133 ventilation studies performed. With the patient's back to the scintillation camera, 10–20 µCi of 133Xe gas were introduced into a closed circuit spirometer system. Images were obtained while the patient held a single deep breath, at equilibrium, and during washout of the tracer.

Pulmonary arteriograms were performed according to the method of Bookstein. Main pulmonary artery injections of approximately 40 cc Renografin 76* (Meglumine and Sodium Diatrizoate) were performed in each case. If a definite embolus was not seen, segmental injections were performed in areas suspicious by history, chest X-ray, lung scan, or the prior main pulmonary artery injection. Segmental injections were performed in 85% of the patients and magnification films were obtained in 20%.

The perfusion lung scans were interpreted as follows:

1) High probability—high probability of pulmonary embolism because of multiple segmental and/or lobar perfusion defects
2) Low probability—low probability of pulmonary embolism because of nonsegmental or equivocally segmental defects, often at the lung bases
3) Other—suggestive of other disease (e.g., emphysema or congestive heart failure)*
4) Normal—no perfusion defects

The perfusion scans were classified without knowledge of the chest X-ray findings.

Xenon-133 ventilation studies were inspected for uniformity and symmetry of ventilation during single breath, equilibrium, and washout phases. Retention of 133Xe beyond 90 seconds after the start of washout was considered abnormal. Significant abnormalities were later correlated with the perfusion images to assess qualitatively regional ventilation and perfusion.

In making the diagnosis of pulmonary embolism, the arteriogram was considered to be definitive. Pulmonary angiograms were interpreted as follows:

1) Acute pulmonary embolism—demonstration of intraluminal filling defects or obstructed arteries with convex proximal margins.
2) Old (organized or chronic) pulmonary embolism—webs, circumferential stenoses, plaques.
3) Other diseases—slowed circulation, narrowed vessels, sparse branching, as may be seen in atelectasis, inflammatory disease or other conditions.
4) Normal

Sixty-four (62%) of the 104 patients had both perfusion scans and pulmonary angiography within 24 hours, and 77 (74%) had both studies within 72 hours. The results in those patients who had both studies within 72 hours did not differ significantly from those in whom the interval was up to ten days, and the figures for all of these studies have been combined.

Parameters observed on chest X-ray are indicated in table 3. Infiltrate, atelectasis, elevated hemidiaphragm, pleural effusion, and local oligemia were considered suggestive of embolism. Other abnormalities were considered totally nonspecific.

### Results

#### Perfusion Scans

Table 1 compares the interpretations of the perfusion scans and pulmonary arteriograms in the 104 patients. The perfusion images were abnormal in 40 (98%) of the 41 patients who had the arteriographic features of acute embolization. Thus the perfusion scan proved to be a highly sensitive technique in the diagnosis of pulmonary embolism. Since the perfusion scans also showed some abnormality in four of four patients with old emboli and 52 of 59 (88%) of patients without embolism,

### Table 1

<table>
<thead>
<tr>
<th>Summary of Perfusion Scan and Pulmonary Angiographic Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perfusion scan</td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>High probability of embolism</td>
</tr>
<tr>
<td>Low probability of embolism</td>
</tr>
<tr>
<td>Other*</td>
</tr>
<tr>
<td>Normal</td>
</tr>
<tr>
<td>Totals</td>
</tr>
</tbody>
</table>

*Registered trademark, Squibb & Sons.

*E.g., atelectasis, inflammatory disease.

*E.g., obstructive pulmonary disease, congestive heart failure.
the mere presence of an abnormality on perfusion scan was not specific for pulmonary embolism.

Of the 41 patients with acute embolism, 35 (85%) had perfusion scans indicating high probability of pulmonary embolism (fig. 1). In five patients, the perfusion images, though abnormal, were considered to indicate low probability of embolization or to be characteristic of another condition: two of these patients had emboli demonstrated by segmental arteriography only (fig. 2). Likewise, in the one patient with a normal scan, segmental arteriography was required to demonstrate a single small embolus in an artery only 2 mm in diameter.

Fifty (85%) of 59 patients without arteriographic evidence of pulmonary emboli had perfusion scans interpreted as normal, other, or low probability. The perfusion scans in the remaining nine patients showed multiple segmental and/or lobar defects suggestive of pulmonary embolism. The nine high probability scans were probably due to prior pulmonary embolism in one case, pulmonary inflammatory disease in two, diffuse interstitial fibrosis in one, mitral valvular disease in one, and bronchogenic carcinoma in one. The cause of the abnormal scan was not known in the remaining three cases, two of whom were treated with anticoagulants for presumptive embolism, despite the normal arteriogram.

The data from table 1 are regrouped in table 2 to demonstrate the sensitivity, specificity, and predictive value of a high probability perfusion scan. For this analysis, only those scans which were interpreted as "high probability of pulmonary embolism" were considered to be positive. It is apparent that the scan and angiographic diagnoses agreed in 87/104 patients (84% accuracy).

Chest X-Rays

Of the 41 patients with angiographically documented acute pulmonary embolism, 93% had some abnormality on chest X-ray (table 3). The most common findings were pleural effusion or infiltrate, each of which occurred in slightly more than half of the patients, while 44% had at least two of the following: pleural effusion, infiltrate, atelectasis or elevated hemidiaphragm. Segmental or lobar oligemia (Westermark's sign) was often difficult to evaluate and was the only sign of embolism on the chest X-ray in only one of the 41 patients with acute embolism.

The correlation of chest X-ray and perfusion scan is shown in table 4. For this analysis seven patients with chest X-ray findings of pneumothorax, diffuse interstitial fibrosis, mass or emphysema, but none of the features considered suggestive of embolism, were included in the normal group. The predictive value of a high probability perfusion scan in association with a chest X-ray showing at least one

![Figure 1](https://circ.ahajournals.org/doi/fig/10.1161/01.CIR.41.1.181)

**Figure 1**

P.B., 28-year-old male. High probability lung scan in massive pulmonary embolism. Perfusion scan: left) anterior view; right) posterior view. Lobar defects in right upper lobe and segmental defects in left lower lobe. Angiogram (not shown) demonstrated a large saddle embolus in the right main pulmonary artery extending into the right lower lobe and an embolus in a basal segmental artery in the left lower lobe. Plain chest X-ray (not shown) showed a pleural-based infarct in the right upper lobe.

*Circulation, Volume XLIX, January 1974*
Figure 2

I.L., 45-year-old male. Low probability lung scan in acute segmental pulmonary embolism. Chest X-ray (not shown) showed cardiomegaly and an infiltrate at the right base. Perfusion scan: left, above) posterior view; left, below) right lateral view. Nonsegmental defect, right base, interpreted as having a low probability of pulmonary embolism. Main pulmonary artery injection (not shown) was normal. Right) Selective injection into the descending branch of the right pulmonary artery. Intraluminal filling defect (arrows) indicative of a thrombus in a 4 mm branch of the lateral basilar segmental artery in the right lower lobe.

Of the features of pulmonary embolism was 87% (33/38), slightly higher than that of the high probability scan alone (table 1). When two features of pulmonary embolism were present on the chest X-ray in combination with a high probability perfusion scan, the predictive value was 100% (17/17). The combination of a normal chest X-ray and a high probability perfusion scan was not specific for pulmonary embolism. Eight such patients were encountered, only four of whom had documented pulmonary embolism. On the other hand, of 18 patients with normal chest X-rays and low probability or other scans, none had documented pulmonary embolism.

Fifteen patients had radiographic evidence of left heart failure and/or cardiomegaly. Seven of these 15 had pulmonary emboli, only four of whom had high probability perfusion scans.

Of the 46 patients with high probability scans, 34 had more extensive involvement on the scan than on the chest X-ray and 25 (74%) of these had angiographic documentation of pulmonary emboli. The remaining 12 patients had equivalent abnormalities on scan and chest X-ray, and 11 (92%) had angiographic confirmation of pulmonary emboli. Of the 41 patients with documented acute pulmonary emboli, 26 (63%) had more extensive perfusion defects than radiographic abnormalities and 15 (27%) had corresponding abnormalities.

In retrospect the chest X-ray was particularly helpful in the interpretation of the scan in five cases. In these patients, perfusion defects could be
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Table 2
Accuracy of High Probability Perfusion Scans

<table>
<thead>
<tr>
<th>Perfusion scan</th>
<th>Number of patients</th>
<th>Pulmonary angiogram</th>
<th>Pulmonary embolism</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulmonary embolism*</td>
<td>46</td>
<td>37</td>
<td>9</td>
</tr>
<tr>
<td>Not pulmonary embolism†</td>
<td>58</td>
<td>8</td>
<td>50</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>104</strong></td>
<td><strong>45</strong></td>
<td><strong>50</strong></td>
</tr>
</tbody>
</table>

sensitivity: true positive rate = \( \frac{37}{46} = 82\% \)

specificity: true negative rate = \( \frac{50}{50} = 85\% \)

accuracy: true positives and true negatives = \( \frac{50 + 37}{104} = 84\% \)

predictive value of positive scan = \( \frac{37}{46} = 80\% \)

predictive value of negative scan = \( \frac{50}{58} = 86\% \)

*Perfusion scans interpreted as high probability.
†Includes perfusion scans interpreted as low probability, other or normal.

explained by chest X-ray evidence of mass, pneumothorax, interstitial fibrosis (fig. 3) or emphysema (fig. 4). None of these patients showed specific angiographic evidence of pulmonary emboli.

Ventilation Studies

Table 5 correlates the ventilation study in 13 patients with the perfusion scan and pulmonary angiography. Of six patients with both perfusion and ventilation abnormalities only one had pulmonary embolism (fig. 5), while of seven patients with normal ventilation and abnormal perfusion, five had pulmonary emboli. With respect to pulmonary embolism, the predictive value of a high probability perfusion scan in association with a normal ventilation study was 100% (5/5), while an abnormal ventilation study in conjunction with a low probability or other perfusion scan predicted the absence of pulmonary embolism in 71% (5/7) of the cases. Of the six patients with pulmonary emboli and ventilation scans, two had radiographic evidence of atelectasis: both had perfusion defects and one had an associated ventilation abnormality.

Discussion

The mortality from pulmonary embolism based on autopsy findings is about 10%,17 so that an established diagnosis of pulmonary embolism implies the need for treatment. Hemorrhagic complications of long-term anticoagulation for pulmonary embolism have been reported in 2 to 15% of patients,18 with a 27% rate in the Urokinase Pulmonary Embolism Trial patients.19 Caval interruption,20 embolectomy,21 and thrombolytic therapy19 are associated with significant morbidity and some mortality. Thus, a confident diagnosis of pulmonary embolism is desirable prior to the institution of long-term anticoagulant therapy, and mandatory prior to operative intervention or thrombolytic therapy. At the same time, it is not practical to perform pulmonary angiography in all patients with suspected pulmonary embolism.

The value of imaging with radiolabeled particles in the diagnosis and follow-up of pulmonary embolism is amply documented.1–5 The technique is noninvasive, relatively simple, and the tracers used are essentially harmless.22 The distribution of the radioactive particles reflects relative pulmonary blood flow23 and makes perfusion lung imaging extremely sensitive in the diagnosis of significant occlusions of the pulmonary vasculature. Perfusion defects, however, are not highly specific and may be caused by a spectrum of pathologic processes in addition to pulmonary emboli.

Table 3
Chest X-ray Findings in Acute Pulmonary Embolism (41 Patients)

<table>
<thead>
<tr>
<th>Findings</th>
<th>Number of patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infiltrate</td>
<td>22 (54%)</td>
</tr>
<tr>
<td>Pleural effusion</td>
<td>21 (51%)</td>
</tr>
<tr>
<td>Atelectasis</td>
<td>11 (27%)</td>
</tr>
<tr>
<td>Elevated hemidiaphragm</td>
<td>7 (17%)</td>
</tr>
<tr>
<td>Two or more of the above</td>
<td>18 (44%)</td>
</tr>
<tr>
<td>Focal oligemia only</td>
<td>1 (2%)</td>
</tr>
<tr>
<td>Cardiomegaly and/or congestive failure</td>
<td>7 (17%)</td>
</tr>
<tr>
<td>Pulmonary arterial hypertension</td>
<td>2 (5%)</td>
</tr>
<tr>
<td>Normal</td>
<td>3 (7%)</td>
</tr>
</tbody>
</table>

*See text and table 3
Figure 3

P.H., 64-year-old female. High probability lung scan in diffuse interstitial fibrosis. Left) P.A. Chest. Cardiomegaly, diffuse interstitial fibrosis and calcified pleural plaque, left base. Right) Perfusion scan, posterior view. Segmental defects in the right and left lower lobes. Pulmonary arteriogram (not shown) was negative for embolus. The diagnosis was confirmed at autopsy.

Figure 4

J.H., 71-year-old male. Emphysema. Left) P.A. chest X-ray shows hyperexpanded lungs, flattened diaphragms and a small heart, attributable to emphysema. Right) Perfusion scan, posterior view. Multiple nonsegmental defects, bilaterally, attributable to emphysema. Pulmonary arteriogram (not shown) with selective lower lobe injections was negative for embolus.
Table 5

Correlation of Ventilation and Perfusion Studies (13 patients)

<table>
<thead>
<tr>
<th>Perfusion</th>
<th>Ventilation</th>
<th>Number of patients</th>
<th>Acute embolism</th>
<th>Other diseases</th>
<th>Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>High probability</td>
<td>normal</td>
<td>5</td>
<td>5</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>abnormal</td>
<td>1</td>
<td>1</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Low probability</td>
<td>normal</td>
<td>2</td>
<td>—</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>abnormal</td>
<td>4</td>
<td>—</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Other</td>
<td>normal</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>abnormal</td>
<td>1</td>
<td>—</td>
<td>—</td>
<td>1</td>
</tr>
<tr>
<td>Totals</td>
<td></td>
<td>13</td>
<td>6</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>

The specificity of the perfusion scan may be improved in several ways, most easily by only considering segmental and/or lobar defects to be indicative of embolism. Defects of this type have previously been shown to correlate with angiographic evidence of embolism in 75% of cases. Our data indicate that even when segmental pulmonary arteriography is the standard for comparison,

Figure 5

G.S., 48-year-old-male. Abnormal perfusion and ventilation scans in acute pulmonary embolus. Left, top) Perfusion scan, posterior view. Segmental defects in the right upper lobe, right lower lobe and left lower lobe—high probability of pulmonary embolism. Right) 133Xe ventilation, washout at 150 sec. Delayed clearance at both bases. Equilibrium phase (not shown) was normal. Left, lower) Selective injection into the right lower lobe. Complete occlusion of the anterior and lateral basilar arteries and partial occlusion of the posterior basilar branch. On the chest X-ray (not shown), a left subpulmonic effusion and discoid atelectasis in the right middle lobe and right lower lobe were present.
interpretation based on multiple segmental defects enabled accurate diagnosis in 87/104 (84%) of the patients (table 2). Looked at another way, in our series, given a scan interpretation of high probability of pulmonary embolism, there was an 80% probability that specific angiographic evidence of pulmonary emboli would be obtained. When the perfusion scan was low probability, other or normal, the probability of detecting pulmonary emboli by angiography was 14%. The predictive value of the perfusion scan will probably differ somewhat from these figures in a less selected series.

A second possible means of enhancing the specificity of the perfusion lung scan is to incorporate the chest X-ray findings. It has been emphasized in the literature that perfusion scans should not be interpreted without a simultaneously exposed chest radiograph, although the role of the chest film has not been clearly defined. Contrary to expectations, our results indicated that a normal chest X-ray in association with a high probability perfusion scan was no more predictive of embolism than the high probability perfusion scan alone (table 4). On the other hand, no patient with a normal chest X-ray and low probability scan had pulmonary embolism. Correlation of extent of disease on scan and chest X-ray likewise was of no discriminatory value.

The chest X-ray proved valuable in explaining perfusion defects secondary to chronic obstructive disease, pneumothorax, and mass lesions. In these cases, perfusion defects could be confidently attributed to processes other than pulmonary embolization.

Radiographic demonstration of a cardiac abnormality, especially left heart failure, indicated that the perfusion scan should be interpreted cautiously (fig. 6). The perfusion scan was correctly interpreted as high probability in only four of seven patients with left ventricular failure and angiographic evidence of emboli.

A third means of enhancing the specificity of perfusion lung scanning is to incorporate the radioactive xenon ventilation scan. The combination of normal ventilation in a region of underperfusion has been reported to enhance the likelihood of pulmonary embolism, while corresponding ventilatory and perfusion abnormalities decrease the probability of pulmonary embolism. In ten of our 13 patients who had $^{133}$Xe ventilation studies the final diagnosis was correctly predicted using the above guidelines (table 5). Moser and coworkers have indicated that in the presence of atelectasis or pulmonary infarction both ventilation and perfusion abnormalities may be found. This may reduce the discriminatory role of the ventilation study, as illustrated in figure 5, a patient with a high probability perfusion scan, abnormal ventilation scan, bibasilar atelectasis, and pulmonary emboli. In a similar patient who also had atelectasis, however, the ventilation scan was normal.

A common clinical problem is the detection of superimposed pulmonary emboli in patients with pre-existing perfusion and ventilation defects attributable to chronic obstructive lung disease. It is
Table 6

Clinically Suspicious Pulmonary Embolism: Role of Angiography

<table>
<thead>
<tr>
<th>Angiography not ordinarily required</th>
<th>Perfusion scan</th>
<th>Chest X-ray</th>
<th>Fraction of patients with documented embolism</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Normal</td>
<td>—</td>
<td>1*/8</td>
</tr>
<tr>
<td></td>
<td>Low probability or other</td>
<td>No signs of embolism†</td>
<td>0/18</td>
</tr>
<tr>
<td></td>
<td>High probability</td>
<td>Two or more signs†</td>
<td>17/17</td>
</tr>
<tr>
<td>Angiography may be required</td>
<td>High probability</td>
<td>No signs of embolism†</td>
<td>4/8</td>
</tr>
<tr>
<td></td>
<td>Low probability or other</td>
<td>At least one sign</td>
<td>7/32</td>
</tr>
<tr>
<td></td>
<td>High probability</td>
<td>Only one sign</td>
<td>16/21</td>
</tr>
<tr>
<td>Angiography usually required</td>
<td>Any abnormality</td>
<td>Cardiomegaly or left heart failure</td>
<td>7/15‡</td>
</tr>
</tbody>
</table>

*S*Single small embolus.

†See text and table 3.

‡These patients are also included in the above groups.

uncertain whether the ventilation/perfusion study is of differential value in these patients. The ultimate role of the ventilation scan in enhancing the specificity of the perfusion scan awaits further experience.

We have assumed that selective pulmonary arteriography is the most specific method in the diagnosis of pulmonary embolism. With this technique, occlusions of vessels as small as 0.5 mm in diameter may be detected. The absolute accuracy of pulmonary arteriography in the diagnosis of pulmonary embolism is difficult to evaluate, particularly since emboli frequently undergo rapid fibrinolysis, but we have not had a proven error where segmental and other refined techniques were utilized.

In our experience, pulmonary arteriography is a relatively safe procedure. Of the 298 patients who had pulmonary angiograms within the last five years, two patients with obstruction of 95 to 98% of their pulmonary vasculature died shortly after injection. In view of the severity of the underlying disease, these deaths cannot necessarily be attributed to the procedure. One patient with pre-existing left bundle branch block developed transient right heart block during catheterization and required pacing for 24 hours. In the Urokinase Pulmonary Embolism Trial, five cases of ventricular tachycardia and one cardiac perforation occurred in 310 right heart catheterizations, all of which were successfully treated.

When based on history, physical examination, and electrocardiogram, the diagnosis of pulmonary embolism is fraught with error. Although a low arterial pO₂ has been considered a useful diagnostic finding, it too lacks sensitivity and specificity.

Selective pulmonary angiography in experienced hands is safe and reliable, but logistic considerations prevent its routine application. It is usually desirable to utilize simpler methods to screen and select those patients requiring pulmonary arteriography. Based on the above considerations, we have tabulated proposed guidelines for using the chest X-ray and perfusion lung scan in selecting patients for pulmonary angiography (table 6). It is apparent from the table that when the perfusion scan and chest X-ray both point in the same direction a confident diagnosis can be made and arteriography is not ordinarily required. Otherwise a considerable degree of diagnostic uncertainty will exist, and arteriography may be indicated. Omitted from table 6 are two additional groups of patients who usually require angiography, namely, those with severe underlying chronic lung disease and suspected embolism, and those who are to have thrombolytic or surgical therapy. In the case of the former group we have insufficient data, while in the latter group the morbidity and mortality associated with the therapy demand as definitive a diagnosis of pulmonary embolism as is possible.

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