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The Role of Contrast Enhanced Computed Tomography in the Diagnosis of Low Density Pulmonary Nodules

Jinkyeung Hahm, Kyuok Choe, Sukhyeon Joo and Myeongjin Kim

Contrast enhanced CT manifestations of 141 pulmonary nodules having internal density less than 40 HU were evaluated to study the prevalence of causative disease and their differential points. Tuberculosis (n=79) was most common, active in 96%. There were 22 cancers, 10 abscesses, 9 paragonimiases, 8 cysts, 7 metastases, 4 aspergillomas without air meniscus sign, and so on. 35% of the benign lesions were greater than 3 cm in diameter and 67% of benign lesions did not show a smooth outer margin. Lung cysts and aspergillomas showed relatively thin peripheral enhanced rim (PER), sharp transitional zone (TZ), a smooth inner border (IB), and homogeneous low densities (LD). Tuberculous nodules tended to be smaller in size with thin PER and most had smooth IB and homogeneous LD. Paragonimiasis, abscess, and cancer tended to present with thick PER and lobulated IB. Lung abscess and paragonimiasis both showed homogeneous LD and narrow TZ. However, in paragonimiasis, multiple locules were seen. Lung cancer showed wider TZ and heterogeneous LD. The size and outer margin of pulmonary nodules as a diagnostic criteria is less useful in LD pulmonary nodule. Therefore, CT can be more useful in differentiating the benign from the malignant lesions by observing a more specific and characteristic pattern of peripheral enhanced rim, transitional zone, inner border, and homogeneity of low density area.

Key Words: Lung nodule, lung tuberculosis, lung abscess, lung paragonimiasis, lung aspergilloma, lung primary neoplasm, Thorax CT

Differentiation of lesions found on plain chest radiographs as malignant or benign pulmonary nodules is critical because of its implication on treatment. In recent years, computed tomographic (CT) densitometry has played an important role in the differential diagnosis of such nodules. If the density is greater than 164 HU or less than 50 HU, the lesion is considered as a benign lesion such as an inflammatory granuloma (Godwin, 1982; Siegelman, 1980; Siegelman, 1986; Lee, 1993). The authors evaluated 141 pulmonary nodules in which the attenuation value of the central low density was less than 40 HU on contrast enhanced CT (CECT) scan. Most of these lesions were benign with active pulmonary tuberculosis being the most common. We experienced few cases of aspergilloma resembling simple cyst. To our knowledge, this is the first report dealing aspergilloma and a large number of pulmonary tuberculosis appearing as a low density pulmonary nodule. However, due to the fair number of malignant lesions found in this study, determination of the true nature of the lesions was sometimes very difficult. Correlation was sought between the CT

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Department of Diagnostic Radiology, College of Medicine, Yonsei University, Seoul, Korea
Address reprint requests to Dr. K.O. Choe, Department of Diagnostic Radiology, College of Medicine, Yonsei University, 134 Shinchon-dong, Seodaemoon-ku, Seoul, 120-752, Korea

findings and the ultimate diagnosis of low density pulmonary nodules and an attempt was made to establish the criteria for the differential diagnosis of these nodules.

METHODS AND MATERIALS

On CECT in 123 patients, a total of 141 low density pulmonary nodules of which had diameters less than 6 cm was studied. This criteria of the size was generally accepted in the past (Fraser, 1989). We defined a low density nodule as a lesion in which an attenuation value of the central low density was less than 40 HU on CECT. When a cavity was present within the nodule, we included in the study those in which the volume of the cavity was less than 25% of the volume of the nodule. However, among these, pulmonary aspergillomas with the typical air-meniscus sign which had no difficulty in diagnosis were excluded (Table 1).

Pulmonary tuberculosis (79 nodules in 66 patients) was the most common disease entity. Its diagnosis was made by detecting acid-fast bacilli (AFB) in the sputum in 33 patients, histologic confirmation through either biopsy or operation in 22, and radiologic and symptomatic improvement after anti-tuberculosis medications in 11. Fiftythree patients were considered to have active tuberculosis because of AFB-positive sputum or changes in the follow-up chest radiographs. In 3 patients, the lesions showed no radiologic changes during the six-month follow-up period and they were considered as stable. The remaining 10 patients were listed as active because of symptoms even though they were lost to follow-up (n=7) or received surgery at the time of detection (n=3).

There were 22 primary lung cancer in 22 patients in whom the diagnosis was made histologically by needle aspiration biopsy, bronchoscopic biopsy or surgery. Eleven patients had epidermoid carcinoma, 8 patients had adenocarcinoma, and 3 patients showed tumor of indeterminate cytology. There were 10 cases of lung abscesses in 8 patients, all confirmed by bacteriology. Among the 8 patients having pulmonary paragonimiasis (9 lesions), 7 were confirmed by serology and 1 by needle aspiration biopsy. There were 4 patients with pulmonary aspergillomas where the diagnosis was made by operation or needle aspiration biopsy in 3 patients and confirmed by serology in 1 patient.

There were 8 cystic lesions in 7 patients consisting of 4 echinococcal cysts (3 patients), 2 traumatic cysts (2 patients), 1 bronchogenic cyst (1 patient), and 1 congenital cystic adenomatoid malformation (1 patient). There were 6 patients with hematogenous metastases (7 lesions) of which the primary lesion being osteogenic sarcoma in 2, choriocarcinoma in 1, adenoid cystic carcinoma from head and neck in 1, and a recurrent primary lung cancer after lobectomy in 1 patient. The remaining two patients had T-cell lymphoma and an inflammatory pseudotumor which were diagnosed by needle aspiration biopsy or surgery. There were 81 male and 42 females and the ages were between 18~76 years (mean=51 years).

The CT scanner used in this study was Philips Tomoscan 310 (Best, Holland) and GE-9800 (General Electric Med. System, Milwaukee, WI). The post contrast study was done with a drip injection of 150 ml of conray-60 (Mallinckrodt, USA). The scan was done in 1 cm slice thickness with 10 mm intersection spacing after breath holding at the patients expiratory phase. High-resolution CT scan was

Table 1. Final diagnosis of 123 patients with low density pulmonary nodules

Diagnosis		No. of pts.
Tuberculosis(Tbc.)		66
Lung cancer		22
Abscess		8
Paragonimiasis		8
Cyst		6
Metastasis		5
Aspergilloma		4
Miscellaneous		2
T-cell lymphoma	1	
Inflammatory pseudotumor	1	

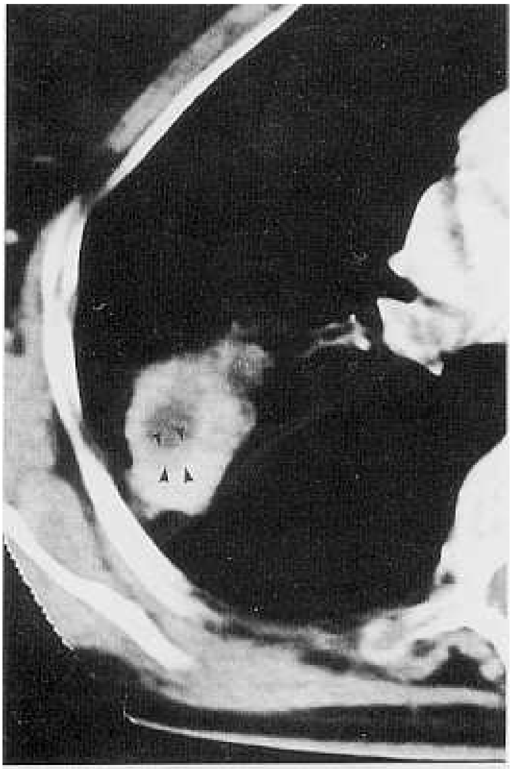

Fig. 1. *A woman 52 years of age with lung abscess. A 3.5 cm sized nodule with an uneven and thick enhanced rim, smooth inner border, and homogeneous central low density. Transitional zone (arrowheads) is well delineated between peripheral enhanced rim and a central low density zone. Thick transitional zone is not typical for lung abscess.*

additionally done in 12 patients (140 kVp/420 mAs, 1.5 mm slice thickness with 5 mm interslice gap). The nodules were evaluated for their location, size, shape, and internal structure. Maximal thickness of the peripheral enhanced rim, thickness of the transitional zone, inner border, and character of low density were the point of evaluation. The measurement was done at the level of the mid portion of the nodule to avoid partial volume effect. The transitional zone was defined as the intermediate zone between the peripheral enhanced rim and the central low density area in which the density becomes intermediate (Fig. 1).

The central low density area was evaluated for homogeneity and multiplicity. When cavitation was present, it was evaluated for its number and whether the location was central or eccentric. If the size of the cavities were smaller than 3 mm, the entity was described as spongiform, and if it is greater than 3 mm, they were described as multiple cavities. In addition to these features, we also evaluated calcifications, air-bronchogram, and satellite nodules.

The statistical analysis was done with the Chi-square test, the Krunskal-Wallis, and one way analysis of variance (ANOVA) test.

RESULTS

Table 2 shows the size and the appearance of the outer margin of the nodules as shown on the CT. As to the size, lung cancer and lung cyst were significantly larger than tuberculosis ($p<0.05$) (Table 2). Among the 111 benign nodules, only 29 (26%) were smaller than 2 cm and 39 (35%) were larger than 3 cm in diameter as compared to 30 malignant lesions in which 21 (70%) had a diameter greater than 3 cm.

The outer margin was smooth in lung cyst (Fig. 2) and in hematogenous metastasis, irregular and ill-defined in abscess (Fig. 1,3) and in paragonimiasis (Fig. 4), and a tendency for lobulation in lung cancer (Fig. 5) ($p<0.05$). Tuberculous nodules, on the other hand, displayed smooth, irregular, ill-defined, or lobulated margins (Fig. 6-8) (Table 2). Three aspergillomas showed smooth margins (Fig. 9) except for one case which showed irregular margins due to surrounding consolidation. Even though this case had active pulmonary tuberculosis as well, it was included in the aspergilloma entity.

Table 3 shows the thickness of the peripheral rim, the transitional zone, the appearance of the inner border, and the presence of air-bronchogram. A total of 7 nodules, 4 of tuberculosis and one each of hematogenous metastasis, aspergilloma, and inflammatory pseudo-

Table 2. CT features of the outer portion of the nodules

	Cyst (n=8)	Aspergilloma (n=4)	Tbc. (n=79)	Paragonimiasis (n=9)	Abscess (n=10)	Cancer (n=22)	Metastasis (n=7)	p-value
Size				3.2±1.3	3.6±0.1	4.1±1.2*	3.0±1.0	<0.05†
Outer margin								<0.05‡
Smooth	3	3	31	0				
Lobulated	4	0	14	3		14	2	
Irregular			10	6				
Spiculated	0	0	24					
Satellite nodule	0		65	7	6	7	0	<0.05‡

Two cases, one T-cell lymphoma and one inflammatory pseudotumor, were not included in this statistical evaluation
Note. Tbc.=tuberculosis
The number in size means the mean±standard deviation
The number in other item means the number of cases
*: significant difference from tuberculosis
†: p-value by Krunskal-Wallis and one way ANOVA test
‡: p-value by chi-square test

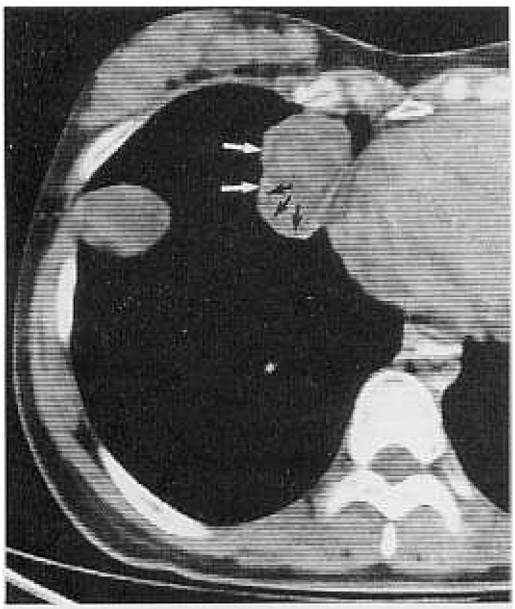

Fig. 2. *A woman aged 27 years with ecchinococcal cyst.*
Two pulmonary nodules, 3 and 4 cm in size, show a thin and evenly enhanced peripheral rim, absence of transitional zone, smooth inner border (black arrows), and a homogeneous central low density, which are characteristic for a cyst. One nodule has a lobulated outer margin (white arrows) because of the thin wall compressed by adjacent bronchovascular bundles.

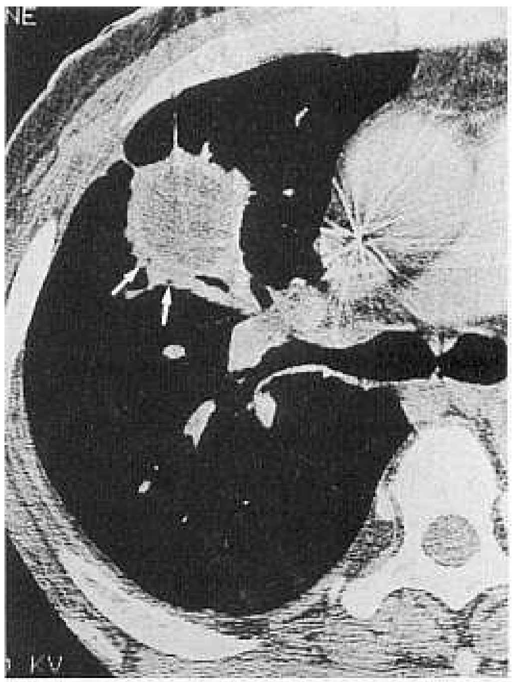

Fig. 3. *A man aged 53 years with leukemia and lung abscess due to invasive aspergillosis.*
A 3 cm sized nodule shows a spiculated outer margin, uneven and thick peripheral enhanced rim with air-bronchogram (arrows), smooth inner border, narrow transitional zone, and a homogeneous central low density.

Table 3. CT features of the enhanced portion of pulmonary nodules

	Cyst (n=8)	Aspergilloma (n=4)	Tbc. (n=79)	Paragonimiasis (n=9)	Abscess (n=10)	Cancer (n=22)	Metastasis (n=7)	p-value
Max thickness (mm)	2.6±2.9	2.0±1.4	5.0±4.3	10.9±8.6	14.0±4.2*	13.4±7.2*	6.5±4.3	<0.05‡
Diff thickness (mm)	2.0±2.5	1.0±1.7	3.3±3.8	8.7±6.8	10.0±5.2†	10.1±6.6†	3.7±3.1	<0.05‡
Transition zone								<0.05#
0	7	3	36	0	3	1	2	
≤ 2 mm	1	1	29	7	5	8	2	
> 2 mm	0	9	14	2	2	13	3	
Air bronchogram	0	1	39	7	7	12	0	
Inner border								<0.05#
Smooth	8	3	58	1	6	8	3	
Lobulated	0	1	21	8	4	14	4	

Two cases, one T-cell lymphoma and one inflammatory pseudotumor, were not included in this statistical evaluation.
Note. Tbc.=tuberculosis
Max thickness: maximal thickness of enhanced rim
Diff thickness: maximal − minimal thickness of enhanced rim
The number in max thickness & diff thickness means the mean±a standard deviation
The number in other item means the number of case
*: significant difference from cyst and aspergilloma
†: significant difference from cyst, aspergilloma, and tuberculosis
‡: p-value by Krunskal-Wallis and one way ANOVA test
#: p-value by chi-square test

tumor, showed totally homogeneous low density nodules without high density peripheral rim on CECT. Their transitional zone was regarded as 0 mm and were classified as nodules with smooth inner border because they also had a smooth outer margin. In the cases of large lung cysts, passive collapse of the adjacent lung parenchyma made it impossible to separate it from the outer margin of the cysts, producing a relatively thick peripheral enhanced rim.

The mean values of the maximal thickness of the peripheral rim were 2.5 mm for aspergilloma, 2.6 mm for lung cyst, 10.8 mm for paragonimiasis, 14.0 mm for abscess and 13.4 mm for lung cancer. In tuberculosis, the mean value of maximal rim thickness was 5.0 mm, which was in-between the cystic lesion which had thin rims and the acute inflammation and malignant lesions which had thicker walls. To measure the evenness of the peripheral rim, we subtracted the minimum from the maximum thickness. The mean values were 1.0 mm for aspergilloma which was most even in thickness, followed by 2.0 mm for cysts, 3.3 mm for tuberculous nodules, 8.7 mm for paragonimiasis, 10.0 mm for abscess, and 10.1 mm for lung cancer. Thus, lung cancer and lung abscess had a tendency to have the most uneven rims ($p<0.05$) (Table 3).

Air-bronchogram was seen in the area surrounding the peripheral rim or the nodule itself in all cases except for the cases of lung cyst and hematogenous metastasis. It was most common in paragonimiasis (n=7, 78%) and lung abscess (n=7, 70%). Although it was statistically insignificant, they were also seen in tuberculosis (49%) and primary lung cancer (55%). One case included in aspergilloma showed consolidation around the nodule, pro-

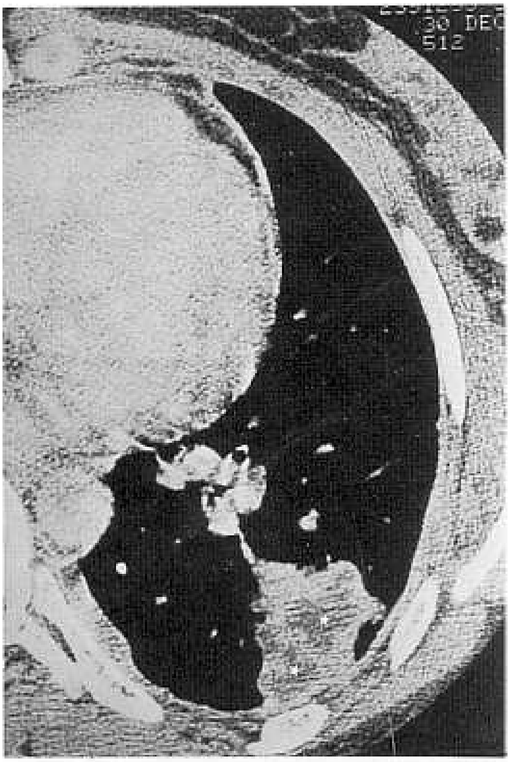

Fig. 4. *HRCT scan from a woman 28 years of age with paragonimiasis.*
A 3.5 cm sized nodule shows an ill-defined outer margin, air-bronchogram, and uneven and thick peripheral enhanced rim, suggesting consolidation. But multiple low density locules (stars) with smooth curved lobulated inner border, narrow transitional zone, and a homogeneous low density are characteristic findings for paragonimiasis.

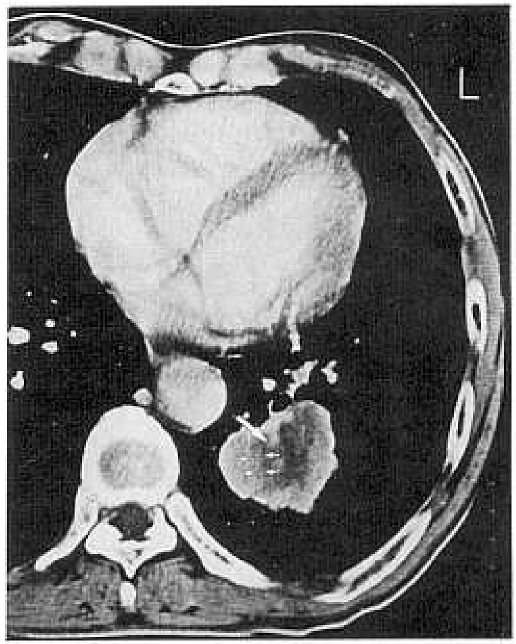

Fig. 5. *A man aged 62 years with adenocarcinoma.*
A 4.5 cm sized nodule show a lobulated outer margin, uneven and thick enhanced peripheral rim, broad transitional zone (small arrows), irregular inner border with mural nodules (single large arrow), and a heterogeneous central low density, compatible with lung cancer.

bably due to active pulmonary tuberculosis. The consolidation was inseparable from the outer wall of the lesion and had air-bronchogram.

The inner border of the peripheral rim was smooth in all cases of lung cyst (Fig. 2) but it was either smooth or lobulated in inflammatory and malignant nodules. Paragonimiasis nodules had a fairly specific lobulated border showing gentle curvature and thin transitional zone which was less than 2.0 mm in thickness (Fig. 4). A lobulated inner border was also seen in 64 % of the malignant lesions but the predominant nodules had a tendency to project into the central portion (mural nodule) (Fig. 5). On the other hand, 72% of the inflammatory lesions such as tuberculosis, abscess, and aspergilloma had a smooth border (Fig. 1, 3, 6, 9) and even when it was lobulated, it had a tendency to be more regular than in malignancy (Fig. 7).

The low density central portion looked homogeneous in all cases of lung cyst, aspergilloma, paragonimiasis (Fig. 2, 4, 9), in 70 % of tuberculosis (Fig. 6, 7) and lung abscess (Fig. 1, 3), and in only 30 % of primary lung cancer and hematogenous metastasis (Table 4). Thus, the malignant nodules had a tendency to show heterogeneous central low density area (Fig. 5) and the difference was statistically significant ($p<0.05$). Seven paragonimiasis lesions (78%)

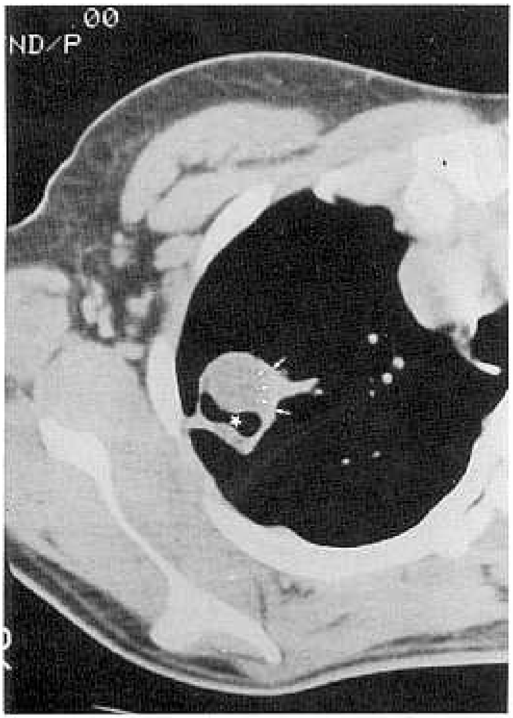

Fig. 6. *A woman aged 37 years with pulmonary tuberculosis.*
A 3 cm sized nodule shows smooth outer margin, thin and even peripheral enhanced rim (arrows), absence of transitional zone, smooth inner border, and a homogeneous central low density. Note the eccentric cavitation (star) with smoothly lobulated border which is not useful criteria to differentiate benign and malignant lesions.

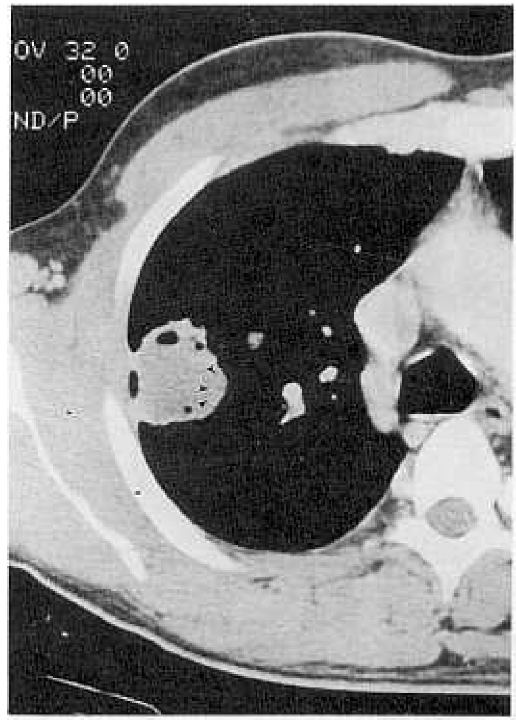

Fig. 7. *A woman aged 48 years with tuberculosis.*
A 3 cm nodule showing a lobulated outer margin, thin peripheral enhanced rim with a lobulated inner border (arrowheads) in parts of the nodule, narrow transitional zone, and a homogeneous central low density are the common findings of tuberculosis. Multiple small cavities are noted between the central low density and the peripheral enhanced rim.

showed multiple low densities within the nodule (Fig. 4) being significantly higher than the other entities ($p<0.05$). Multiple low densities were seen in 9% to 43% of the patients with tuberculosis (Fig. 8), abscess, cancer, and metastasis. Multiple low densities were not seen in lung cyst and aspergilloma.

Cavities within the nodule was seen in 42% in tuberculosis and 11-20 % in abscess, cancer, cyst, and paragonimiasis (Table 4). Cavitary nodules were accepted in this study only when the cavity volume was less than 25% of the overall volume of the nodules. Because of this, the incidence of cavity among the different groups was considered meaningless in our study. However, the cavity had a tendency to be eccentric when it was small regardless of the pathology (Fig. 6, 7). The spongiform cavity was seen most often in pulmonary aspergilloma (50%), but was also observable in other entities except in hematogenous metastasis (Table 4). Satellite nodules were seen in 82 % of the lesions representing inflammatory nodules such as abscess, paragonimiasis, and tuberculosis, but they were also seen in 32% of the lung cancer patients. Satellite lesion were not seen in lung cyst and hematogenous metastasis. The inner border of the cavity was

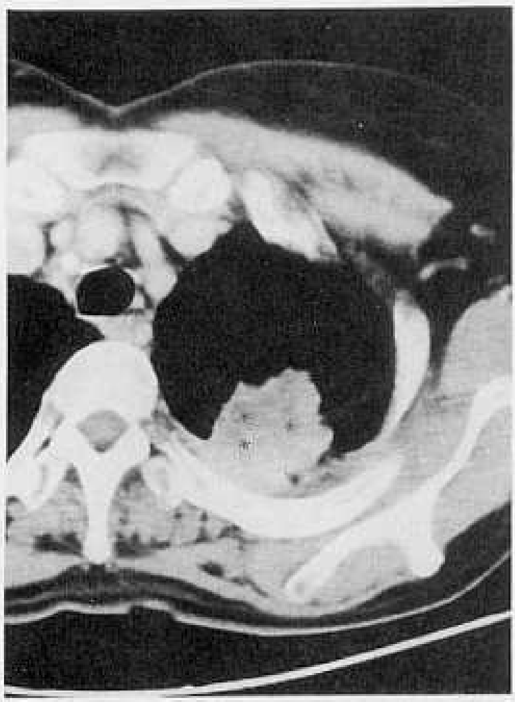

Fig. 8. *A woman aged 57 years with tuberculosis. A 3.5 cm sized nodule shows an ill-defined outer margin, thick and uneven peripheral enhanced rim, lobulated inner border, relatively thick transitional zone, and heterogeneous low densities with multilocularity (asterisks). Air-bronchogram is not seen in this slice but was identified in other contiguous section. These findings may be due to caseous necrosis within the consolidation.*

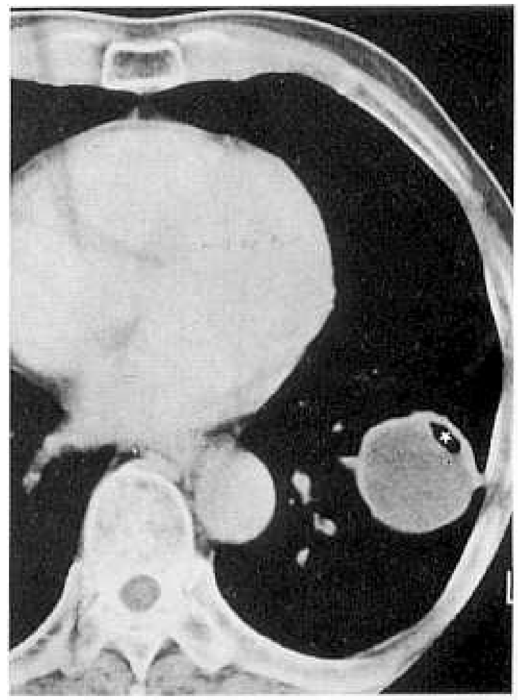

Fig. 9. *An alcoholic man aged 61 years with aspergilloma within a cavity. Chest radiograph showed a 5 cm sized nodule with eccentric cavity. CT shows smooth outer margin, a thin and even enhanced rim, absence of a transitional zone, smooth inner border, and a homogeneous central low density. Air collection (star) between the cavity and fungal ball simulates eccentric cavitation in plain radiograph.*

smooth in all cases of cysts, aspergilloma, and paragonimiasis, but only in 50% of tuberculosis and abscess, and only in 20% of lung cancer, although there was no statistical significance.

We divided the entire group into benign (n =111) and malignant (n=30) lesions and analyzed the accuracy of the measured parameters in predicting the benign or malignant nature of the disease (Table 5). The lesion was considered benign if the nodule was smaller than 3.0 cm, maximum thickness of the enhancing peripheral rim less than 5.0 mm, the difference between the thick and thin part of the rim less than 5.0 mm, transitional zone less than 2.0 mm, and had a smooth and round inner border and was accompanied by satellite nodules and air-bronchograms. The sensitivity, specificity, and accuracy for each criteria is shown on Table 5. Among them, the most useful criteria were the maximum thickness and evenness of the enhanced rim, thickness of the transitional zone, homogeneity of the low density area, and the presence of satellite nodules.

Table 4. CT features of low density pulmonary nodules

	Cyst (n=8)	Aspergilloma (n=4)	Tbc. (n=79)	Paragonimiasis (n=9)	Abscess (n=10)	Cancer (n=22)	Metastasis (n=7)	p-value
Density								<0.05*
Homongeneous	8	4	55	9	7	7	2	
Heterogeneous	0	0	24	0	3	15	5	
Number of low density								<0.05*
Single	7	4	71	2	8	20	4	
Multiple	1	0	8	7	2	2	3	
Cavity								
Smooth	1	2	17	1	1	1	0	
Lobulated	0	0	16	0	1	4	0	
Central	0	0	4	0	0	0	0	
Eccentric	1	2	27	1	2	4	0	
Sponge form#	1	2	2	1	2	2	0	

Two cases, one T-cell lymphoma and one inflammatory pseudotumor, were not included in this statistical evaluation.

Note. Tbc.=tuberculosis

The number means the number of case

*: p-value by chi-square test

#: Sponge form; more than two cavities, less than 3 mm in size

Table 5. Accuarcy of diagnostic criteria to predict benignancy

Criteria	Sensitivity	Specificity	Accuracy
Size ≤ 2 cm	0.261	0.900	0.397
≤ 3 cm	0.649	0.700	0.660
Smooth outer margin	0.342	0.767	0.443
Satellite nodules	0.712	0.733	0.716
Air-bronchogram	0.495	0.567	0.511
Max thick ≤ 5 mm	0.595	0.800	0.638
Max thick ≤ 15 mm	0.955	0.200	0.794
Diff thickness ≤ 5 mm	0.694	0.600	0.674
Transition zone ≤ 2 mm	0.847	0.533	0.780
Smooth inner border	0.694	0.633	0.681
Homogeneous low density	0.757	0.700	0.745

Max thickness: maximal thickness of enhanced rim

Diff thickness: maximal − minimal thickness of enhanced rim

DISCUSSIONS

It is generally accepted that a pulmonary nodule with characteristic calcification and absence of interval change over a two-year period is considered benign. None of our cases showed calcification. It is reported that benign lesions usually have a smooth outer margin and only 2.0% are larger than 3.0 cm in size

(Zerhouni, 1986). But in our study, 35.1% of benign nodules were larger than 3.0 cm in size making size an unreliable index of malignancy. Furthermore among the 111 benign lesions in our series, only 34.2% presented smooth border, and the remainders showing irregular ill-defined border in 22.5%, lobulated border in 19.8%, and spiculated border in 23.4%. Therefore, the size, calcification and the appearance of the outer margin of these low density pulmonary nodules were not so helpful in differentiating benign from malignant lesions.

Recently, CT densitometry using the reference phantom have shown that even though there was an absence of gross calcification, increase in density due to microcalcifications can also be a finding suggestive of a benign nodule (Siegelman, 1980; Godwin, 1982; Levi, 1982; Khan, 1991). In analyzing internal densities of 36 pulmonary nodules on non-contrast enhanced CT scan, Godwin *et al.* (Godwin, 1982) stated that the average HU for the malignant lesion was 69.5 HU and 175.9 HU for the benign. In their report, the range of the HU of the malignant lesions was 45-110, most having values in the fifties. On the other hand, benign lesions had CT values ranging from 12-920 HU which shows broader range. In our study, 78.7% of the 141 low density pulmonary nodules were benign.

In our study, central low density was either due to inflammation, tumor necrosis, fluid within the cyst, or a fungal ball. All these lesions may eventually produce cavities when the liquid content within the tumor or the cyst is expectorated with the exception of aspergillomas. The morphology of the enhanced rim and the character of inner wall seen on the CECT scan was similar to their diagnostic criteria used on the plain chest radiograph. In differentiating a benign from malignant cavity, the most helpful findings on plain chest radiographs were the maximum thickness of the cavity wall and the character of the inner border. In the analysis of 61 cavitary nodules seen on plain chest radiographs, Woodring et al (Woodring, 1980) stated that 95% of the cavities with maximum wall thickness less than 5 mm, and 50~73% of those within the range of 5~15 mm were benign and that 85~95% of those with maximum thickness greater than 16 mm were malignant. In our study, 64 (89%) of 72 nodules with maximum thickness of the peripheral enhanced rim (PER) being less than 5 mm, 42 (79.2%) of 53 nodules with PER between 6~15 mm, and 5 (45.5%) of 11 nodules with PER greater than 16 mm turned out to be benign nodules. This is slightly different from Woodring's findings (Woodring, 1980; Woodring, 1983) which may be due to the fact that there were proportionately more benign particularly active inflammatory lesions than malignant lesions in our study. Using similar diagnostic criteria employed by Woodring, Choi *et al.* (Choi, 1990) evaluated 37 cavitary nodules (19 benign, and 18 malignant) on CT. They stated that the thickness of the enhanced rim was more accurate than the thickness of the cavity wall in differentiating benign and malignant lesions. Correlating with pathologic findings, they stated that the enhanced area seen in cavitary lung cancer was the area with live tumor cells (Choi, 1990). In tuberculosis, it represents an area of granulation tissue (Sakai, 1992).

On plain chest x-rays, cavities with smooth inner wall were almost always benign and those with thick and irregular wall were suggestive of lung abscesses and primary lung cancer. In lung cancer, the so-called mural nodules could be observed on the inner border which are thought to be due to partial necrosis and focal tumor growth (Fraser, 1989). Characteristics of the inner wall seen on plain chest radiographs were almost identical to those observed on CT in each disease category. Smooth inner wall was seen in all cases of lung cyst, in 70~75% of aspergilloma, abscess, and tuberculosis but only in 33~38% of malignant nodules. Ninety percent of paragonimiasis had gently lobulated inner border.

The transitional zone between the peripheral enhanced rim and the central low density area was less than 2 mm in 83.6% of lung cysts, aspergilloma, abscess, paragonimiasis, and tuberculosis. However, 57.1% of malignant lesions had transitional zone wider than 2 mm. Thus, thickness of the transitional zone can be helpful in the differential diagnosis of benign and malignant lesions. Central low density was homogeneous in all the cases of lung cyst, aspergilloma, and paragonimiasis, and in 70% of tuberculosis and abscesses, but only in 30% of primary lung cancer and hematogenous metastasis. Homogeneity can also be an accurate diagnostic criteria suggesting benign lesion. Zwirowich *et al.* stated that 55% of benign and 20% of malignant lesions had homogeneous central low densities, but they also included the cavitation and air-bronchograms in the low density criteria (Zwirowich, 1991). Multiple lobules of low densities were not seen in lung cyst or aspergilloma, but they were seen in 78% of paragonimiasis and were significantly higher than that seen in other diseases.

Compare to the usefulness of chest radiograph in differentiating a cavitary lesion, morphology of the peripheral enhanced rim can be more useful in defining the low density pulmonary nodules before formation of the cavity or when cavity is still partially filled with fluid or debris. Small cavities within low density area were not really helpful in differentiating diagnosis. Moreover, only CT can give the information on the transitional zone and the homogeneity of central low density.

Three of the 4 aspergilloma could not be differentiated from pulmonary cysts because the character of the enhanced wall represents that of the cavity or bronchiectasis containing fungus ball. Aspergilloma as a cause of low density pulmonary nodule has not been reported but there is a report stating that aspergillous fungus ball with air-meniscus sign within the cavity can be seen on the CT scan as a spongiform mass or a homogeneous low density (10~40 HU) (Roberts, 1987; Hahm, 1992). Even though spongiform cavitation was seen in 50% of aspergilloma, it was not useful in defining the nature of the nodules.

In tuberculosis, the maximal thickness of peripheral enhanced rim was greater than in lung cyst and aspergilloma but thinner than in other diseases. It had a tendency to show relatively narrow transitional zones, smooth inner border and homogeneous low densities. In low density tuberculous lesions, most of them were active lesions and their low density was attributed to caseous necrosis or liquefaction. Siegelman *et al.* stated that most of pulmonary nodules with high CT density were inflammatory granuloma (Siegelman, 1980; Siegelman, 1986). The difference from our result is that most of their cases were a stable lesion.

Paragonimiasis had a thick peripheral rim and showed a lobulated, gently curved inner border which was unique, and multiple locules of low density (Fig. 3). In paragonimiasis, larva or egg obstructs the small vessels in the surrounding parenchyme causing ischemic necrosis (Im, 1992). In our study, the low density areas were considered to be either unruptured worm cysts or necrosis in progress.

Lung cancer and abscess had a thick enhanced rim and irregular inner border, making it extremely difficult to differentiate it from each other. They have different feature in the outer border, thickness of the transitional zone, and homogeneity of the central low density. Cavity develops in 2~16% of primary lung cancer and this finding is more common in squamous cell carcinoma than in other cell types (Zielinski, 1984). Heterogeneous internal density within adenocarcinoma has also been reported by Kuriyama *et al.* (Kuriyama, 1987) and Kuhlman *et al.* (Kuhlman, 1988).

Satellite nodules were not observed in the hematogenous metastasis and cyst. They were seen in 82% of the benign lesions and they were also seen in 32% of primary lung cancer which may be due to obstructive pneumonia and surrounding infiltration of cancer cells (Kim, 1988). Air-bronchogram could be detected on HRCT scan in primary lung cancer when bronchi were present within the mass, if the adjacent lung parenchyma was compressed by the mass, or if malignant cells infiltrated the submucosal layer of the peribronchial area (Gaeta, 1991). Branching or linear air-bronchograms were seen in areas adjacent to the high density peripheral rim but these findings were not so helpful in the differential diagnosis in our series.

In conclusion, conventional criteria used in the diagnosis of solid pulmonary nodules such as calcification and size, and appearance of the outer margin were not very helpful in determining benign or malignant nature of low density pulmonary nodules. For these, more informations can be obtained by using the CECT scan which can better define the inner architecture of the nodules such as thickness of the enhanced rim, transitional zone, and homogeneity of the low density area. Therefore, in the diagnosis of low density pulmonary nodules, CECT scan is more useful than the plain chest radiography in defining the true nature of the lesions.

REFERENCES

Choi HS, Choe KO, Lee JD, Choi SS: Differential diagnosis of cavitary lung masses by computed tomography. *The Journal of Korean Radiological Society 26: 164-1169, 1990*

Fraser RG, Pare JAP, Pare PD, Fraser RS, Genereux GP: *Diagnosis of diseases of the chest.* 3rd ed. Philadelphia, Saunders, *1989, 1342-1440*

Gaeta M, Pandolfo I, Volta S, et al: Bronchus sign on CT in peripheral carcinoma of the lung: *value in predicting results of transbronchial biopsy. 157: 1181-1185, 1991*

Godwin JD, Speckman JM, Fram EK, et al: Distinguishing benign from malignant pulmonary nodules by CT. *Radiology 144: 349-351, 1982*

Hahm JK, Choe KO, Choi HS: Radiologic manifestations of pulmonary aspergilloma: special emphasis on atypical manifestation. *The Journal of Korean Radiological Society 28: 197-204, 1992*

Im JG, Whang HY, Kim WS, Han MC, Shim YS, Cho SY: Pleuropulmonary paragonimiasis: radiologic findings in 71 patients. *AJR 159: 39-43, 1992*

Khan A, Herman PG, Vorwerk P, Stevens P, Rojas KA, Graver M: Solitary pulmonary nodules: comparison of classification with standard, thin-section, and reference phantom CT. *Radiology 179: 477-481, 1991*

Kim KY, Choe KO: Analysis of computed tomographic manifestations of primary lung cancer. *The Journal of Korean Radiological Society 24: 1025-1034, 1988*

Kuhlman JE, Fishman EK, Kuhajda FP, Meziane MM, Khouri NF, Zerhouni EZ: Solitary bronchioloalveolar carcinoma: CT criteria. *Radiology 167: 379-382, 1988*

Kuriyama K, Tateishi R, Doi O, Kodama K, Tatsuta M, Matsuda M: CT-pathologic correlation in small peripheral lung cancers. *AJR 149: 1139-1143, 1987*

Lee KS, Song KS, Lim TH, Kim PN, Kim IY, Lee BH: Adult-onset pulmonary tuberculosis: findings on chest radiographs and CT scans. *AJR 160: 753-758, 1993*

Levi C, Gray JE, McCullough EC, Hattery RR: The unreliability of CT numbers as absolute values. *AJR 139: 443-447, 1982*

Roberts CM, Citron KM, Strickland B: Intrathoracic aspergilloma: role of CT in diagnosis and treatment. *Radiology 165: 123-128, 1987*

Sakai F, Sone S, Maruyama A, et al: Thin-rim enhancement in Gd-DTPA enhanced MRI of tuberculoma: a new finding of potential differential diagnostic importance. *J Thoracic Imaging 7: 64-69, 1992*

Siegelman SS, Khouri NF, Leo FP, Fishman EK, Braverman RM, Zerhouni EA: Solitary pulmonary nodule: CT assessment. *Radiology 160: 307-312, 1986*

Woodring JH, Fried AM: Significance of wall thickness in solitary cavities: a follow up study. *AJR 140: 473-474, 1983*

Woodring JH, Fried AM, Chuang VP: Solitary cavities of the lung: diagnostic implications of cavitary wall thickness. *AJR 135: 1269-1271, 1980*

Zerhouni EA, Fram EK, et al: CT of solitary pulmonary nodule. *AJR 135: 1-13, 1980*

Zerhouni EA, Stitik FP, Siegelman SS: CT of the pulmonary nodule: a national cooperative study. Radiology *160: 319-327, 1986*

Zielinski KW, Kulig A: Morphology of the microvascular bed in primary human carcinomas of lung. *Pathol Res Pract 178: 243-250, 1984*

Zwirowich CV, Vedal S, Miller RR, Muller NL: Solitary pulmonary nodule: High-resolution CT and radiologic-pathologic correlation. *Radiology 179: 469-476, 1991*