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Part II: Single Exposure Energy Subtraction Chest Radiography in the Diagnosis of Pulmonary Cancer

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第2部：肺癌診断における一回撮影エネルギー差分法

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胸部の1回撮影エネルギー差分法をFCRのImaging Plateを金属フィルターの前後に密着して置く撮影システムで行ったところ，臨床に応用可能な画像を得る事ができた．そこで肺癌が疑われた患者200人についてこの方法を施行し，通常のFCR画像にどれくらいの情報を加えることが可能か調べた．その結果，気道系の異常の認識，肋骨下に重なった小結節陰影の描出がsofttissue image（bone cancelled image）で，肋骨転移の発見と結節陰影内石灰沈着の有無判定がbone image（softtissue cancelled image）で有効で，合計21%の症例で新しい情報として，また確認がなされた．

この1回撮影は“動き”と言うアーチファクトを無視できる．胸部のエネルギー差分法が技術的に完成されたX線検査となり臨床に広く利用される時期においても，あくまでルーチンX線検査の一つであり，特殊検査とはなり得ない．したがって，被検者の一般状態に基づく失敗作を少なく恒常的に読影可能画質を比較的低い被曝で得る事が可能な1回撮影法が本命と考える．しかし，その得られる画質向上を目的とした技術面での研究が必須である．さらに，完成時でも，softtissue imageとbone imageの2画像のみでなく，著者が今回行った通常の画像と2枚の差分画像を並べた読影システムにならざるを得ないと考えている．

Introduction

Dual-energy scanned projection radiography has evolved from CT localization technology[1)2)]. Only a few clinical studies have been reported using this technique[3)4)5)6)]. The eventual clinical application of dual-energy subtraction radiography (DES) could not be understood from these literatures. To clarify the situation, a preliminary investigation was performed comparing the DES images of a chest phantom obtained by a single-exposure technique relative to similar images obtained with the dual-exposure/dual-kVp technique. We then assessed the clinical value of DES in a large group of patients suspected of pulmonary cancer by comparing bone and soft tissue emphasized DES image pairs relative to conventional computed radiographs.

* The imaging plate is the image receptor used with the FCR system[9)].

There are two methods for producting DES image pairs: These are the single-exposure/detector technique and the dual exposure technique. In the dual-exposure technique, two separate radiographs are obtained using different kVp's. Registration of the two original images is difficult due to the presence of respiratory, cardiac and other motions. In the single-exposure/dual-detector technique, two detectors are placed one behind the other. The detectors may be conventional radiographic films with energy separation provided by a metallic energy selective X-ray filter[7] or by the use of a combined high and low atomic number detector pair[8]. Other detector pairs may be used. In this method, the first detector records a signal which is preferentially derived from the lower energy components of the X-ray beam. The beam, in passing through this detector, and perhaps an additional filter, is hardened before it reaches the second detector. The signal recorded by the second detector is mainly derived from the higher energy components of the beam.

Materials and Methods

Our single exposure subtraction method utilizes the Fuji Computed Radiography System (FCR) manufactures by the Fuji Photo Film Co. Ltd., Japan. As shown in Fig. 1, the radiographs for single-exposure subtractions are taken using a 35cm×35cm cassette containing a front imaging plate (IP)*, a 1mm thick copper filter and two back imaging plates. The DES cassette is exposed in exactly the same manner as any film-screen cassette. Conventional radiographic equipment and techniques were used for this study.

The energy subtraction image pair consists of a bone cancelled image and a softtissue cancelled image. These images are computed using the following procedure:

1. The two rear image plates are combined to produce a high energy image with an improved Signal to Noise Ratio (SNR). A weighted sum is obtained from the images on IP (II) and IP (III). The weighting factors T1 and T2 are chosen relative to the X-ray dose absorbed by each IP:

$$Shv=(T1\times Shv1+T2\times Shv2)/(T1+T2)$$

where

Shv is the output high energy image signal
Shv1 is the high energy image signal from IP (II)
Shv2 is the high energy image signal from IP (III)
T1, T2 are proportional to the doses received by IP (II) and IP (III) respectively.

2. Energy subtraction is performed using Brody's[10] Compton/Photoelectric decomposition methodology.

$$Ssub=K1\times Shv-K2\times Slv+K3$$

where

Ssub is the energy subtraction image signal
Shv is the high energy image signal with improved SNR
Slv is the low energy image signal from IP (I)

The weighting factors K1 and K2 are chosen so that the representation of either bone or softtissue is cancelled. The signal offset K3 is chosen so that the output signal is optimized to the FCR system's display range.

3. Unsharp masking is performed on each image to enhance the display of high frequency information. The images are then processed to invert the grey scale and improve contrast. They are finally printed on to film as minified images (17.5cm×17.5cm). The elapsed time for the processing of each energy subtracted image is approximately 20 minutes on our prototype FCR system.

Preliminary experiments were performed using anthropomorphic chest phantom (Humanoid Systems, U.S.A.). Single exposure radiographs were obtained at 140 kVp, 100mA, 0.25 sec. using a 10:1 grid and a 200cm FFD. Comparison dual exposure images were obtained by radiographing the phantom at 80 and 140 kVp. Image plates and Brody's method were used for this latter series.

In the clinical study, erect posteroanterior chest radiographs of patients with suspected pulmonary cancer were obtained using the same technical factors as in the single exposure phantom study. Two hundred and six patients in our hospital were studied during the period from November 1984 through December 1985. The following studies were performed on this group of images:

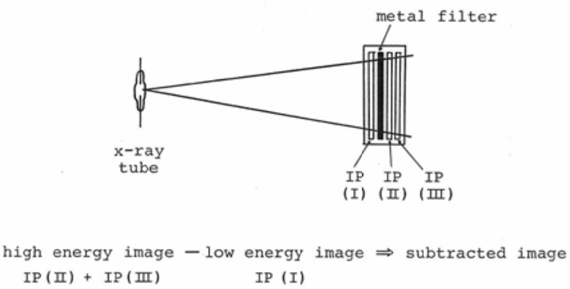


Fig. 1 Shematic representation of single exposure energy subtraction technique.

Table 1 The anatomical regions for scoring and the list of clinically relevant objects on the subtracted films

On the softtissue film
I. softtissue of thoracic wall
II. mediastinum and hilar regions
III. trachea and major bronchi
IV. pleura
V. lung fields
a) nodular shadows
b) consolidation and atelectasis
c) septal line (lymphangitic metastasis)
On the bone film
I. skeletal thorax
(ribs, spine, scapula, clavicle)
II. lung fields
calcification in nodular shadows

1. Technical quality of the subtractions.

2. Radiographic diagnosis of probable pulmonary cancer performed by interpreting a non-subtracted digital radiograph: The radiograph was obtained from the front imaging plate in the cassette. These images were processed to resemble conventional film-screen radiographs.

3. Evaluation of the bone (softtissue cancelled) and softtissue (bone cancelled) subtraction radiographs: This evaluation was made in relation to the unsubtracted digital radiographs obtained as described above. The single and DES images were therefore obtained from the same radiographic exposure.

The subtraction images were reviewed with three radiologists and scored as follows:

(++) The abnormality was seen on one or both of the two subtractions: It was not seen on the unsubtracted radiograph.

(+) The subtractions confirmed or clarified the findings on the unsubtracted image. These images helped to establish the existence of suspicious findings on the conventional images or helped in the evaluating the nature of these findings.

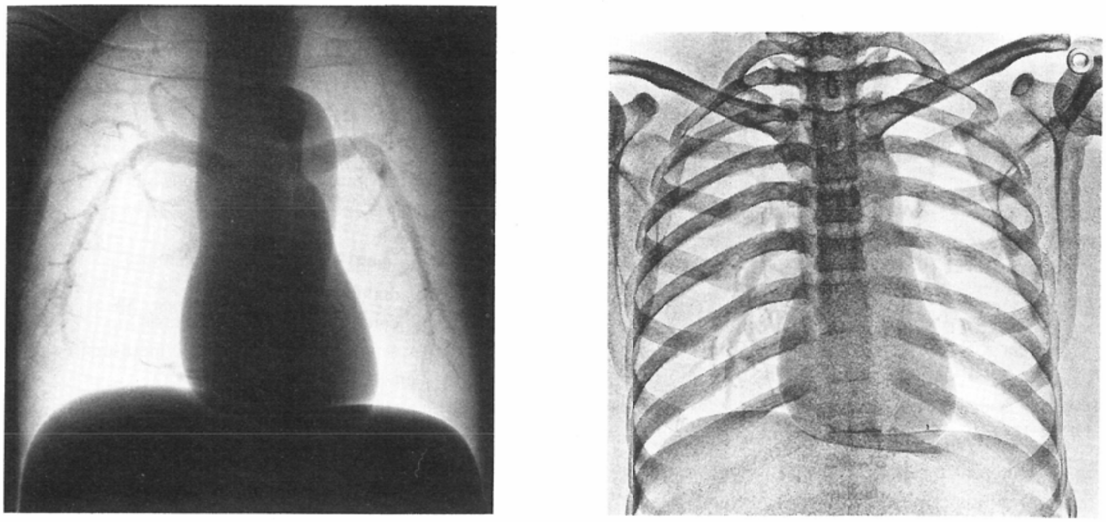
(0) The subtractions added no new information to the findings on the conventional image.

When there was intraobserver disagreement, the score which was agreed upon by two observers was employed.

The images were evaluated for abnormalities of several kinds in several anatomical regions. The scoring regions and a listing of clinically relevant objects are given in Table 1.

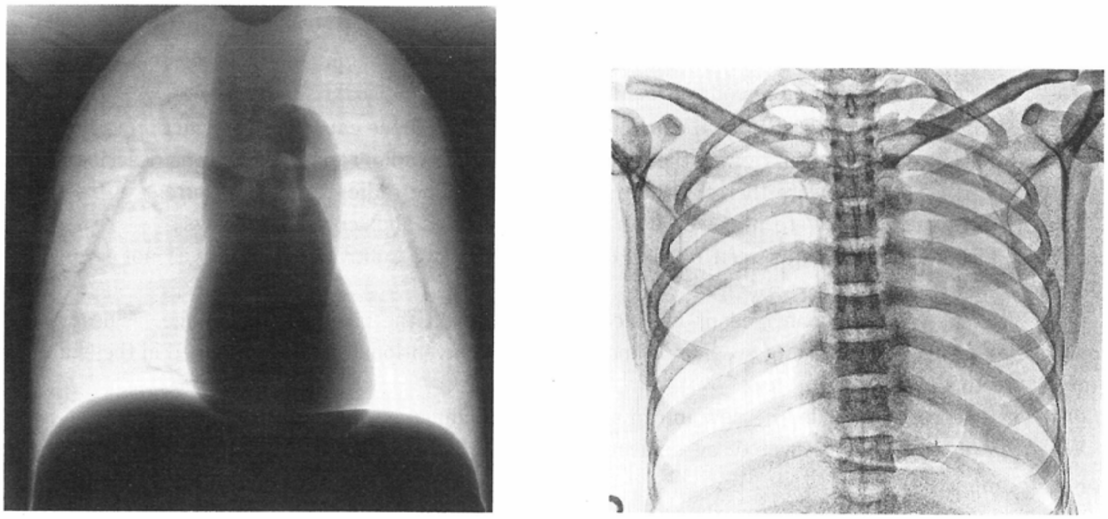
Results of the Phantom Study

A comparison of the subtracted image pairs of the phantom clearly shows that both of the single-exposure images are noisier than the corresponding images obtained using the two-exposure technique; furthermore, there is less complete subtraction using the single-exposure technique. There are residual pulmonary vascular and heart shadows on the bone image (Fig. 2B) as well as residual rib and clavicular shadows on the softtissue image (Fig. 2A); there are no registration artifacts around the pulmonary vessels, hemidiaphragma and heart in the single-exposure images. Even in the motionless phantom study, misregistration artifacts are recognized in the two-exposure images around the left side of the heart and the hemidiaphragm on the bone image (Fig. 3B).



A. softtissue film (bone cancelled film). B. bone film (softtissue cancelled film).

Fig. 2 Chest phantom radiographs with single exposure.



A. softtissue film. B. bone film.

Fig. 3 Chest phantom radigraphs with dual exposure.

Results of the Clinical Study

1. The subtracted images of 6 patients were excluded from the study due to poor image quality.

2. No abnormality was seen in 34 patients, a definite abnormality was seen in 153 patients. In the remaining 13 patients, it was impossible to determine whether or not pathological findings on the images were indicative of pulmonary cancer.

3. On 153 of the soft tissue images there were no cases which demonstrated superiority of the subtractions in the thoracic wall, mediastinum and hilum, pleura, or in cases of non-nodular parenchymal disease (Regions I, II, IV Vb, Vc respectively). In the trachea and major bronchi (III), a total of 11 of 32 images (34%) demonstrated effectiveness of the softtissue image (Table 2, Fig. 4). In the case of lung nodules (Va), 134

Table 2 Abnormality of trachea and major bronchi

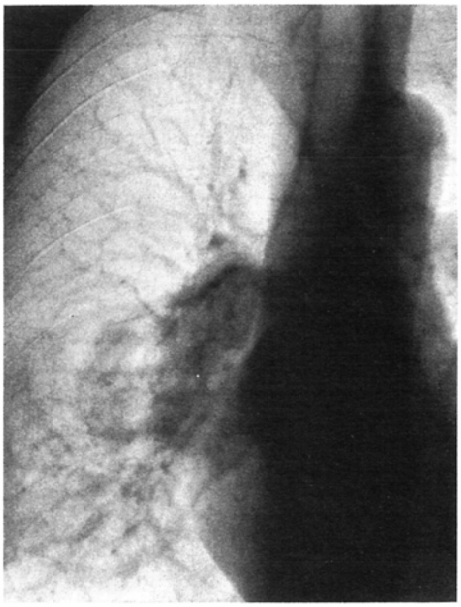
	obstruction and narrowing	dislocation		
(卄)	0	1	1	11(34%)
(+)	4	6	10	
0	4	17	21	
			32	

Table 3 The detection of nodular shadows

	≦10mm	11～≦20mm	21～≦30mm	31mm<	Total	
(卄)	1	3	0	0	4	17(13%) (13 patients)
(+)	5	7	1	0	13	
0	22	21	37	37	117	
	28	31	38	37	134	

excluded patients with multiple (N>4)nodules.

A. conventional digital film.

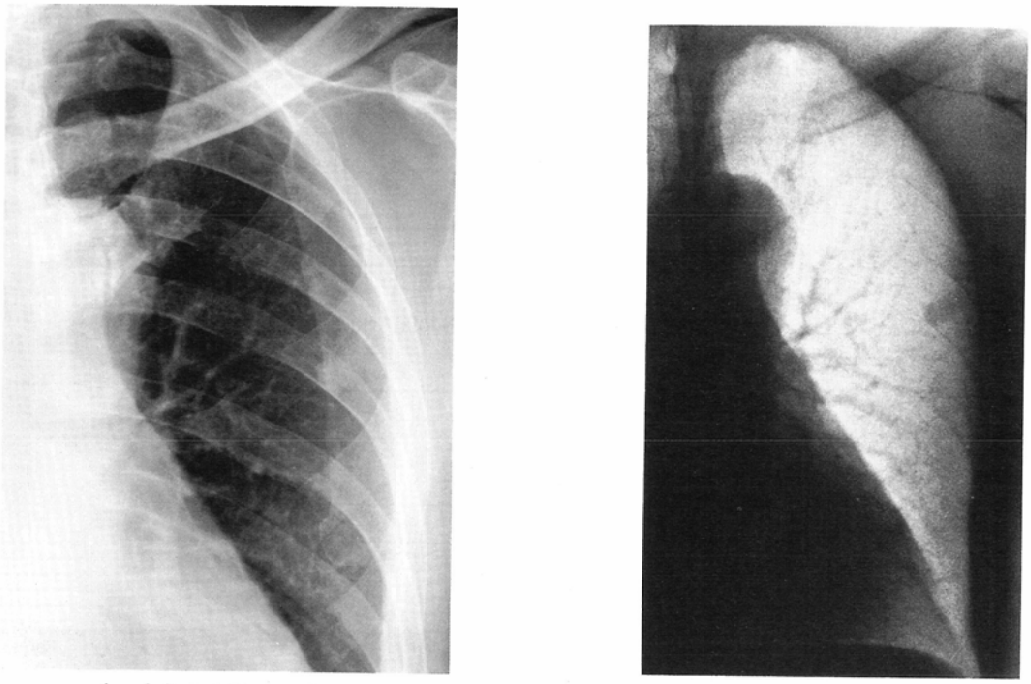


B. softtissue film: narrowing of intermediate bronchus is easily visible comparing with A.

Fig. 4 Chest radiographs of patient with right small cell cancer.

uncalcified nodules were examined (Table 3). Patients with multiple (N>4) nodules were excluded. The softtissue DES images were confirmatory or clarifying in 13 of these nodules. Four nodules were only seen on DES images. All but one of these nodules were less than 20mm in size and were mainly obscured by rib shadows on conventional images. In a total of 17 nodules in 13 patients, the softtissue images might be of diagnostic value (Fig. 5, Fig. 6).

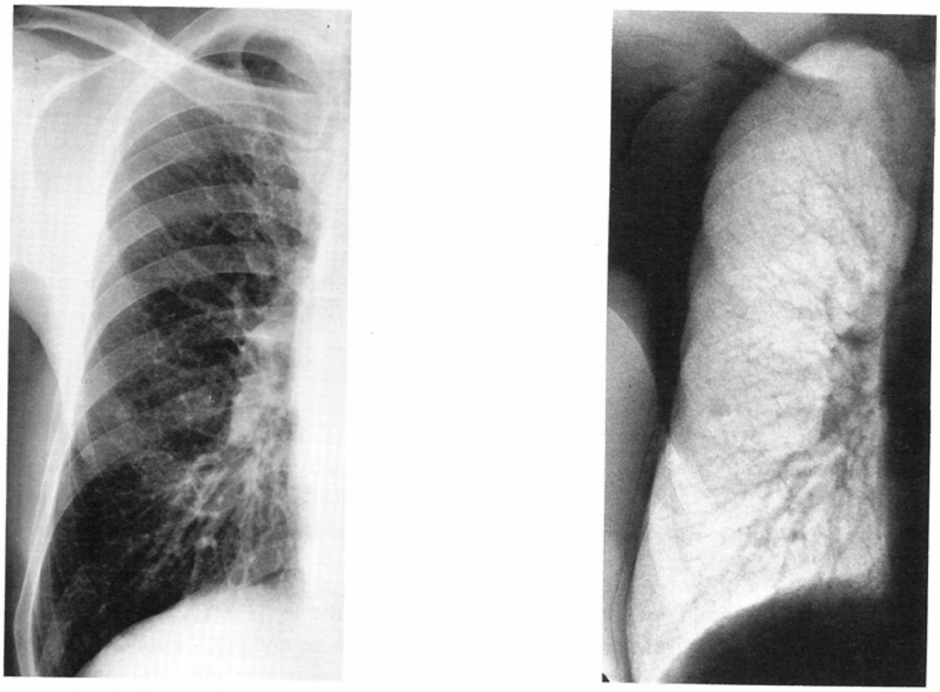
On 153 bone films, there are 24 osteolytic lesions of the ribs and no osteoblastic lesions (Table 4). In 8



A. conventional digital film : pulmonary nodule is obscured by rib and scapula.

B. softtissue film shows clearly the lesion.

Fig. 5 Chest radiographs of patient with leftmiddle lung nodule (adenocarcinoma).



A. conventional digital film : a small lesion is partially obscured by ribs.

B. softtissue film shows the lesion more clearly.

Fig. 6 Chest radiographs of patient with right low middle nodule (hamartoma without calcification).

Table 4 Bony abnormality (rib defect)

(卄)	1	8(33%)
(+)	7	
0	16	
	24	

no abnormality in other parts of skeletal thorax except ribs.

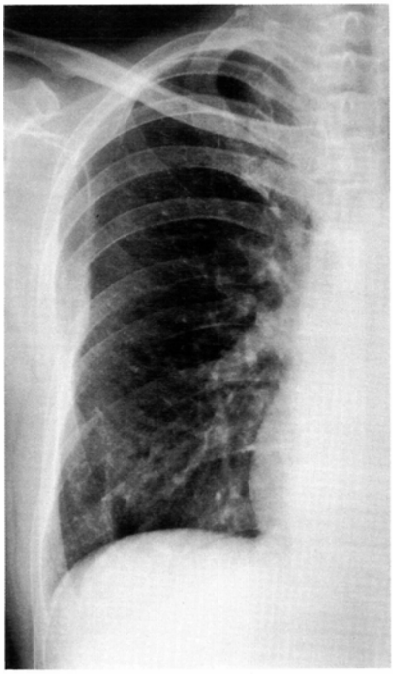
Table 5 Calcifications in pulmonary nodules

(卄)	4	11(8%)
(+)	7	
0	123	
	134	

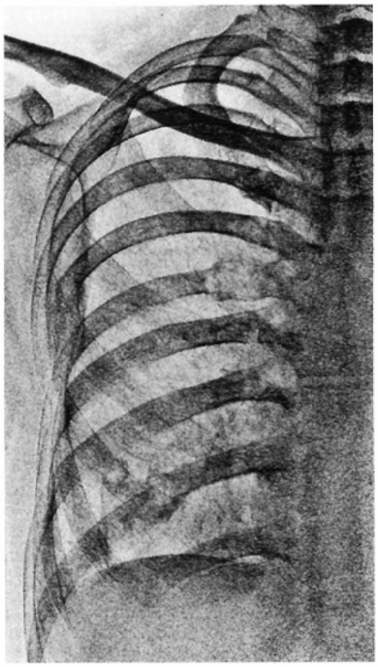
Table 6 The number of abnormal findings (and patients)in which the subtracted films were usefull

	Softtissue image							Bone image		Total
	I	II	III	IV	V			I	II	
					a	b	c			
(卄)	0	0	1	0	4	0	0	1	4	10
(+)	0	0	10	0	13	0	0	7	7	37
	11 (11patients)				17 (13patients)			8 (8patients)	11 (11patients)	47 (42patients)*

*a patient with which abnormalities of trachea and of rib coexist both.

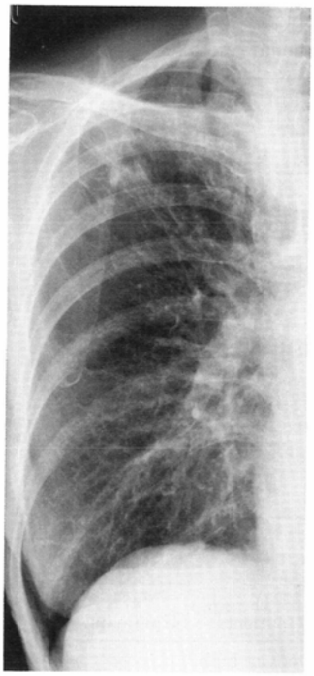


A. conventional digital film : lytic metastasis of right 6th rib is demonstrated.

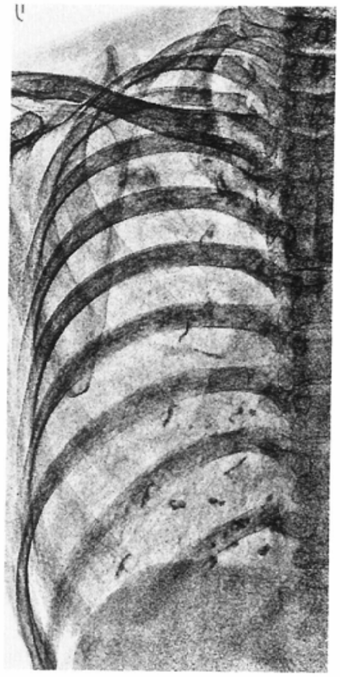


B. bone film : lytic lesion of 7th rib, which is obscured by hilar shadow on A, are particulary well detectable.

Fig. 7 Chest radiographs of patient with two osteolytic lesions of ribs (6th and 7th).

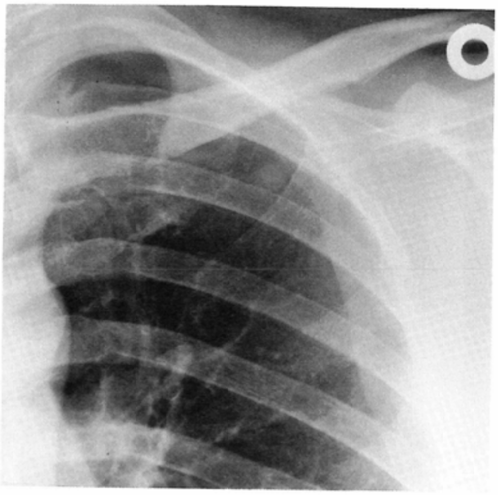


A. conventional digital film.

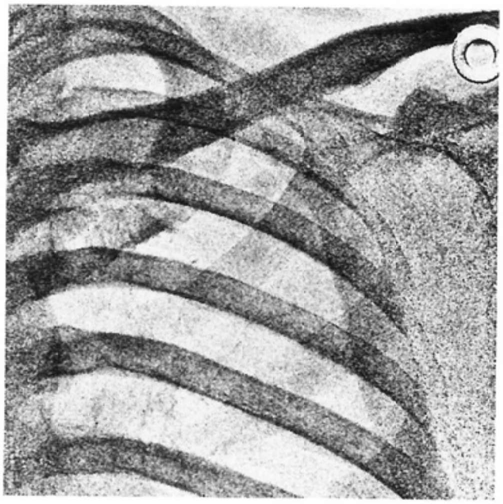


B. bone film confirms calcification in the lesion which is suspicious on A. Multiple costochondral calcifications are well demonstrable also.

Fig. 8 Chest radiographs of patient with right upper nodule (granuloma).



A. conventional digital film.



B. bone film shows diffuse calcification in the lesion as new information which is not visible on A.

Fig. 9 Chest radiographs of patient with small nodule in left upper lung field.

of these 24 lesions, which obscured by surrounding softtissue, bone images were effective for detection (Fig. 7). There were 134 nodules in which calcification could not be definitely identified on the conventional images. These nodules were examined on the bone image (Table 5), the DES images were useful for the detection of calcification in 11 of these nodules (Fig. 8). In 4 of these 11 nodules, the calcifications were detectable only on the bone DES image (Fig. 9).

Discussion

The single-exposure/dual-detector technique reduces misregistration problems in DES imaging at the cost of reduced image quality. Although the FCR system is capable of compensating its detection parameters for the different X-ray fluence recorded by each detector, it cannot compensate for the reduced SNR's due to the low doses received by the rear image plates. In addition, the copper separation filter produces a less complete subtraction than the two-exposure/dual-kV technique. The imperfect separation results in insufficient cancellation ; for example, the residual pulmonary markings on bone films and the residual rib shadows on soft tissue films. The low photon fluence reaching the rear IP's results in increased noise and poor demonstration of objects behind high contrast structures. For example, the spine is not visualized behind the heart silhouette on bone films. In addition, the overall single exposure subtractions are noisier than the corresponding two exposure images. Low contrast objects or those objects such as septal lines which require high spatial resolution are less well visualized using the single-exposure technique.

The single-exposure technique is useful in clinical chest films where misregistration artifact limits the applicability of the two-exposure technique. Our overall results are presented in Table 6. In our series, DES provided the following results: The visualization of airways is enhanced and the detection of pulmonary nodules lying under the ribs is improved on the softtissue image (Tables 2, 3). The visualization of osteolytic rib lesions is enhanced, and the evaluation of calcification in nodules is confirmed in the bone image (Tables 4, 5). In this series of 200 patients with suspected lung cancer DES provided new, clinically useful information in 10 cases (5%). In an additional 37 cases (16%) DES provided improved information which supported the findings on the conventional images. These results support the clinical use of subtracted films. DES appears to offer radiologists the advantage enhanced conspicuity of the leisons by reducing the distraction of "unwanted" structure[10)11)].

The presence of radiographically demonstratable calcification in a solitary pulmonary nodule is the most important determinant of benignancy. The positive identification of diffuse or minimal calcification is not always possible with conventional radiographic techniques or with conventional tomography[12)]. In 11 nodules, the bone films are useful for detecting calcification, especially in those 4 nodules where calcification was not seen in the plain film. At this point, the advantage of DES over conventional radiography have been previously reported by Brody[3)] and Kruger[13)]. The question arises as to whether the ability of the detection of calcification in nodules on the subtracted films holds diagnostic significance.

The detection of metastatic disease involving the bony thorax is an important factor in the therapy of pulmonary cancer. The potential of DES for lesion detection in comparison with bone scintigraphy must await further study. DES may also be useful to detect small nodules in lung fields and to demonstrate abnormalities of the airways without the use of techniques such as conventional or computed tomography.

These results support the concept that DES might be a part of plain roentgenographic examinations using standard X-ray systems. Two DES images (bone image and softtissue image) might be placed next conventional image on the view box and provided for interpretation at same time, even in future when DES system become an accomplished modality technically. That is the reason why our scoring method is employed for the clinical evaluation of subtracted images in this study. It could provide additional information at low cost and with rapid throughput. Furthermore, it is important to be simplified and reproductive for the clinical utilization. There were only 6 cases (2.9%) in which DES was technically inadequate in our series. So, the single exposure technique looks promising. Future efforts must be directed toward the investigation of the technique and the improvement of image quality.

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