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Stereozonography in Mediastinum and Pulmonary Hilum using A Compensating Filter and Computed Radiography

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Abstract In the case of chest tomography, particularly the mediastinum and the pulmonary hilar tomography are difficult to the matter without exposure time factor. For the reason, these region are much used rectilinear tomography for the shortening of exposure time. But, as for the visuability of the morphology, it is advisable for these region to use in multi-directional tomography. However, it is in need of long exposure time.

Therefore, authors experimented with stereozonography of short exposure time by circular movement using a compensating filter and computed radiography. Shifting distance of X-ray tube for stereography was 10% of distance between focus and object. The exposure time and exposure angle were 0.6 sec, $2\theta=3^\circ$ respectively.

As a result, this stereozonography was excellent in the visuabilities of mediastinal region, including bronchovascular shadows, and could examine in details is on images of these region.

By using the compensating filter, the improved image quality of mediastinal region was obtained.

On addition, using computed radiographic system, even if artifact araised from disagreement between form of the compensating filter and mediastinal region, authors could easily restored non-diagnostic image by orverall density manipulation and unsharp mask filtering.

Key Words: Stereozonography, Mediastinum and Pulmonary hilum, Compensating filter, Computed radiography

1. Introduction

Thoracic tomography cannot be discussed without reference to the time factor. This is particularly true in examination of the madiastinum and pulmonary hilum, in which the patient's respiration, as well as aortic motion, may result in blurring of the tomographic image. For this reason, fast exposure using a linear movement are generally employed. However, when tomography is performed using a linear movement, the tomographic width varies depending upon the region examined, and upon the distribution and orientation of bronchi and blood vessels. This is because the bronchi and blood vessels course radiately from the hilum. In addition, mediastinal lines such as the azygos, esophageal and paravertebral lines are oriented in the axial direction, which causes them to be superimposed in the axial linear movement which is generally employed. The same is true for anterior and posterior junction lines. For these reasons, conventional thoracic tomography is inferior in visualizing these structures. On the other hand, multi-directional tomography is superior in assessing the entire morphology of the bronchi, blood vessels, mediastinum, or tumor lesions, although a long exposure time is required. Taking all these factors into consideration, a fast-exposure, multi-directional exposure system is required for thoracic tomography, particularly for examinatins of the mediastinum and pulmonary hilum.

The authors performed stereozonography of the mediastinal and hilar regions using a circular movement and an exposure time of 0.6 seconds.

A compensating filter was used in examination of the mediastinal and hilar regions to reduce exposure to the lung fields, providing a beam limiting effect for the improved mediastinal image quality[1)2)]. The ulilization of computed radiography (CR) permitted free setting of image parameter, i.e., sensitivity, latitude, gradation, etc. Furthermore, frequency and gradation processing could be performed even after the examination was completed. The authors utilized a combination of filtering and CR techniques, and attempted to optimize both for examinations of the mediastinum and hilum.

2. Materials and Methods

The stereozonography was carried out with Toshiba tomographic Units (LGU-1), tube voltage at 80 kVp, motion is circular, the exposure time 0.6 seconds, Fuji computed ratiographic system, Fuji imaging plate ST with size 10" × 12".

1) Movement distance of the scanned object

In stereozonography, the scanned object is moved by the tabletop in orthogonal direction for transverse axis. The movement distance was set to 10 cm, which was approximately 10% of the focus-to-object distance.

2) X-ray exposure angle

The X-ray exposure angle for stereozonography is considered optimum when rib shadows do not obscure the areas to be examined and the tomographic layer is deep enough to include all the structures of the hilar region. The vasscular diameter is greater than 3.0 mm and the bronchial diameter is greater than 5.0 mm in hilar region[3)]. Based on our 10 years of experience in mediastinal and hilar tomography using a compensating filter, virtually the entire hilar region is contained within an area 3.0 cm deep anterior and posterior to the bifurcation of the trachea, if it is set as the center of the ROI.

Authors first determined the tomographic width using spiral test wire 3.0 mm in diameter spaced at 10 mm intervals.

3) Constructing the compensating filter

Fig. 1 shows the points which were traced to determine the mean density distribution curve of the thoracic region. This curve was then used as the basic data for constructing the compensating filter. The six points used were the intermediate area between the apex of the lung and the left primary arch, the center of the left pulmonary arch, the bifurcation of the trachea, the left upper trunk and the center of the left tertiary and quarternary arch.

In order to determine the thickness of alumi-

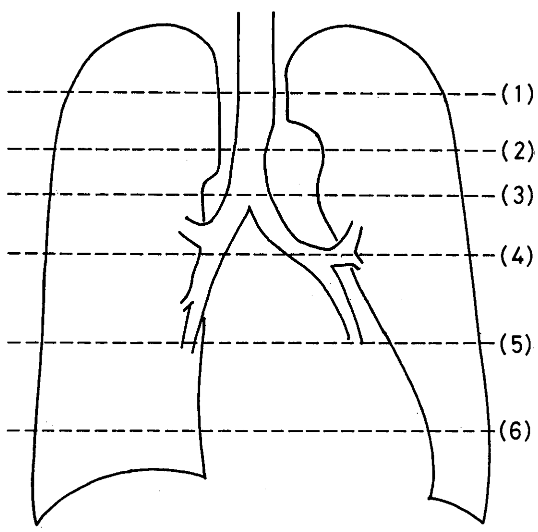

Fig. 1 Measurements situation for the density distribution for a chest zonogram using microdensitometer.

num which would provide accurate density compensation for regions denser than hte bifurcatin of the trachea, equalizing the density of these regions to that of the bifurcation, an aluminum density attenuation value was obtained by stacking 18 thick acrylic resin sheets in a stepped shape which was very closely matched to the absorption characteristics of the mediastinum.

Fig. 2 shows the characteristic CR curve which was used in this study. Data was acquired in the mean value system semi-auto mode (constant data recording latitude and automatic sensitivity setting) using the L3.0 data recording latitude (dynamic range 10^3). In addition, the measurement values obtained by a microdensitometer (SAKURA PDM-5, B.BR) was given in term of diffusion density (FUJI Model 301).

Exposure must be perfomed twice for stereozonography of this study. Therefore, it was necesary for us to test how well differences in respiratory phase could be tolerated. Testing using a 20 cm thick stepped paper phantom with 1.0 mm diameter wires spaced at 50 mm intervals in 5.0 mm steps was performed. In addition, an exposure technique which maintained one tomographic plane constant on the center of the phantom was performed, while the other tomographic plane was changed in increment of 2.0 cm.

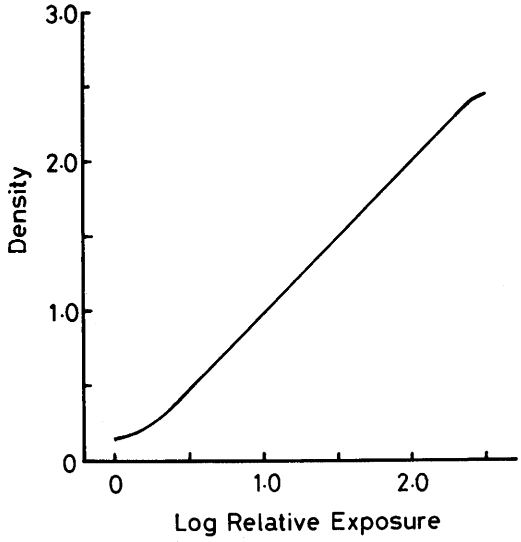

Fig. 2 Characteristic curve of computed radiography in data processing to make of a compensating filter.

3. Result

Fig. 3 shows the relationship between the exposure angle and tomographic width obtained using our wire phantm. At an exposure angle $2\theta=3°$, the tomographic width obtained using 3.0 cm diameter wire was 75.2 mm. The tomographic width obtained using wire is considered the maximum tomographic width which can be obtained under these conditions. However, smaller width value are obtained clinically, and these tomographic width cover virtually the entire hilar region at the exposure angle $2\theta=3°$. Therefore, authors investigated stereozonographic exposures at $2\theta=1$ to $10°$ using a human phantom. Authours found that if the exposure is made using an exposure angle $2\theta > 3°$, costal shadow are visible. However, this is not a problem when interpreting the image. Taking these findings into consideration, the optimum exposure angle was determined to be $2\theta=3°$

Fig. 4 shows the mean density curve obtained by tracing the six points shown in Fig. 1 with a microdensitometer. Zonograms of 15 cases wre obtained, setting the density at the bifurcation of the trachea at 1.0. Fig. 5 shows a density attenuation curve using aluminum. The density of 1.59 was obtained with an aluminum thickness of 0 mm by drawing vertical line from the point where the density for 20 mm aluminum thickness crossed 1.0 as shown by an arrow in the

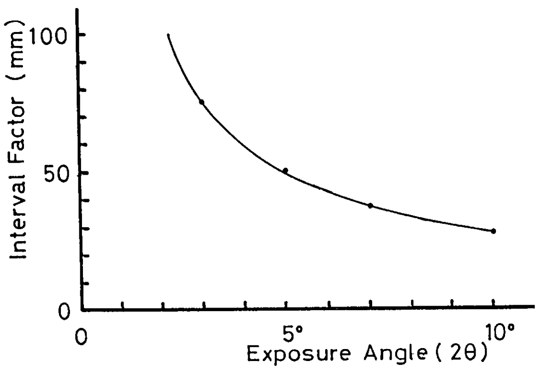

Fig. 3 Relationship between exposure angle and interval factor for 3 mm ∅ wire.

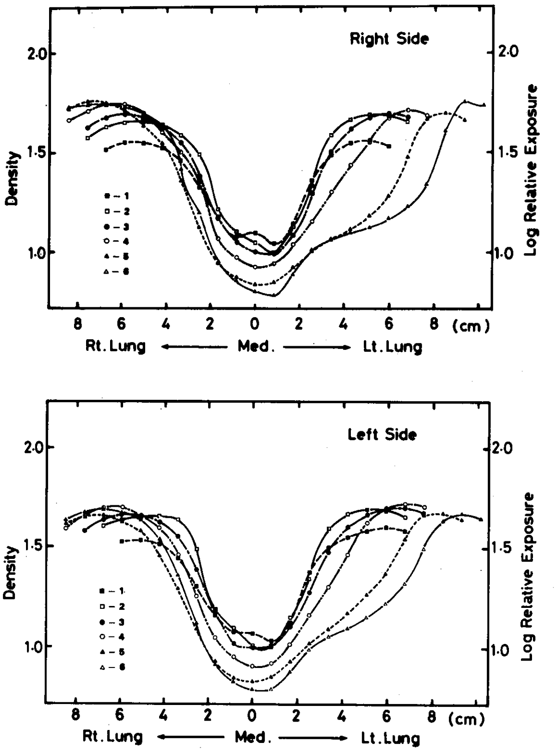

Fig. 4 Distribution curves of the mean density value in 15 cases of zonograms.

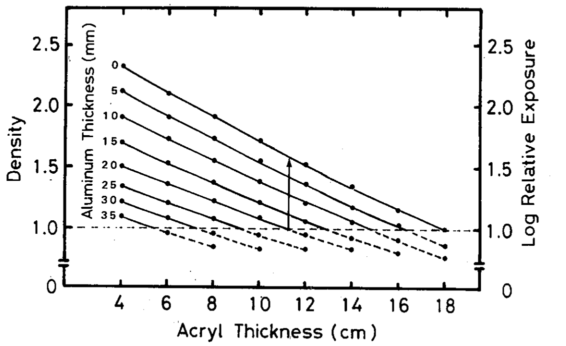

Fig. 5 Density reduction curves in Aluminum with acrylic phantom.

figure. In other words, the thickness of aluminum which compensated the basic density of 1.59 to equal 1.0 was determined to be 20 mm.

Fig. 6 shows alminum thickness 5, 10, 15 mm, and so on, which were obtained in the same manner. These were the aluminum thicknesses required for compensation for each basic density of the mediastinal and hilar regions to equal the density level at the bifurcation of the trachea. Fig. 7 shows the alminum thickness required to compensate for the density of the whole mediastinal and hilar regions obtained in Fig. 4 and 6 so that the density above equaled that of the bifurcation of the trachea. The exposure is shown on the right vertical axis in Fig. 4, 5 and 6. However, since the CR image was output based on a linear gradation curve with gamma = 1.0, the density was represented by the exposure[5]. Fig. 8 shows the compensating filters constructed. Fig. 9 shows a linear movement stereozonogram obtained using the compensating filter. The exposure factor used were an exposure angle $2\theta=7°$ and an exposure time of 0.42 seconds. The tomographic plane was set at the bifurcation of the trachea. Sirial stereoscopic observation of the bronchial and vascular distribution was achieved, and image quality was judged acceptable for clinical diagnostic applications. Fig. 10 shows a stereozonogram obtained using a circular movement. The tomographic plane is set to the bifurcation of the trachea. Case (a) shows the image obtained without using a cmpensating filter. Case (b) shwos the image obtained using the compensating filter. Fig. 11 shows clearly the stenosis of left main bronchus due to lung cancer (squamous cell carcinoma).

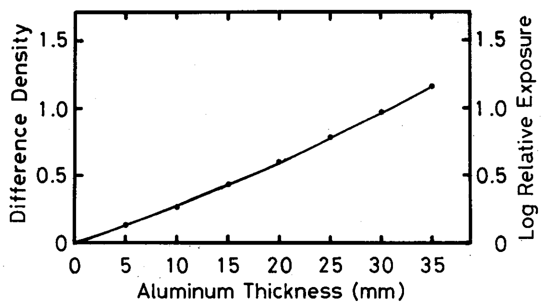

Fig. 6 Relationship between density and thickness of Aluminum to reduce the overdensity of the mediastinum and hilar zonogram to the density of the tracheal bifurcation.

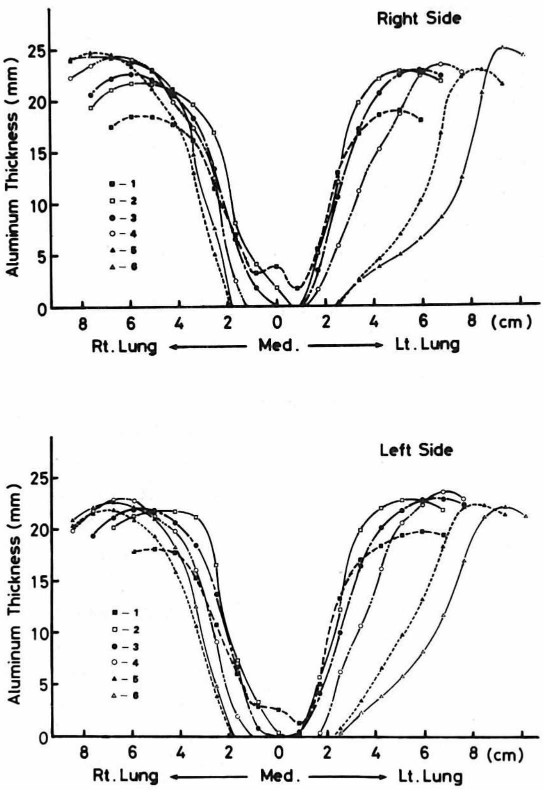

Fig. 7 Relationship between each point in these regions and thickness of Aluminum to reduce the over density of the mediastinum and pulmonary hilus zonogram to the density of the tracheal bifurcation.

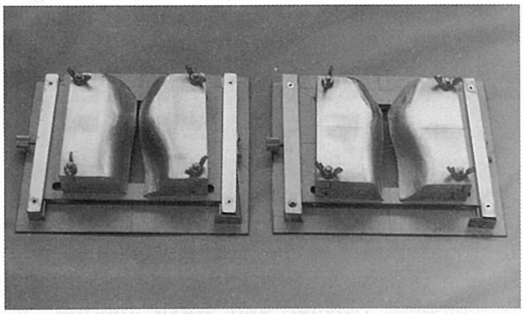

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Fig. 8 The compensating filter is compensated a ratio of 1:1 in X-ray exposure difference on imaging plate between the mediastinum and the lung field.

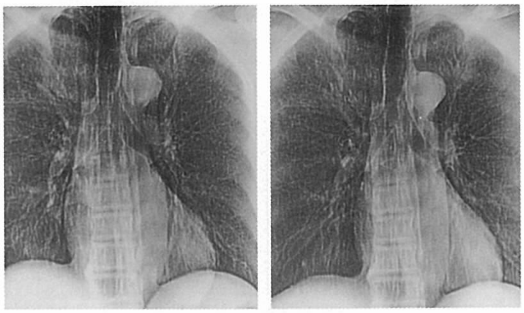
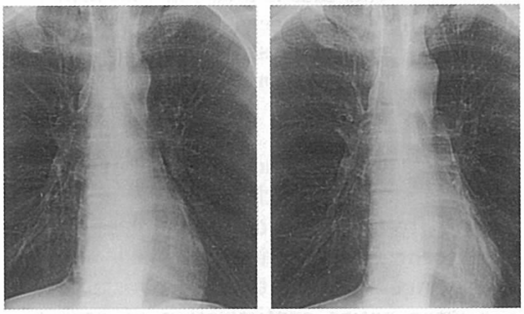
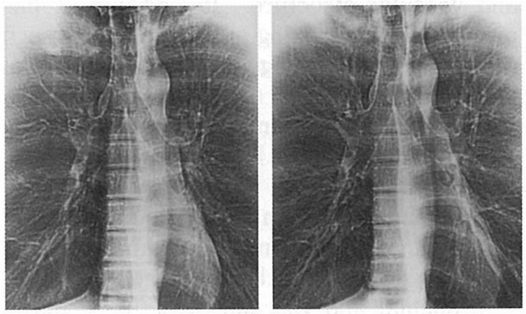


Fig. 9 Stereozonograms with rectilinear direction to use of the compensating filter.



(a)



(b)

Fig. 10 Stereozonograms with circular direction.
(a) shows the case without the compensating filter.
(b) shows the case with the compensating filter.

4. Discussion

The results of experimental and fundamental studies were reported in Fig. 1-7 respectively. Fig. 8; compensating filter, and clinical cases in Fig. 9, 10 and 11. Linear movement stereozonography was used by

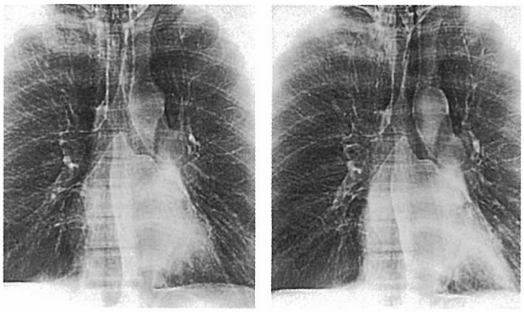


Fig. 11 Stereozonograms with circular direction of the case with compensating filter.
This case is a 60 year-old man with left lung cancer.
This image shows clearly the stenosis of left main bronchus and mediastinal lines.

Watanabe, et al., who have reported on it usefulness[5)6)]. Nevertheless, this technique suffers from several disadvantages, such as significant linear shadows which interfere with image interpretation and poor ability to show the entire configuration of bronchial and vascular structure. In addition, it has problems in visualizing mediastinal lines such as the azygos, esophageal and paraverterbral lines. Fig. 10 case (b) shows the image obtained using the compensating filter. Unlike the case shown in Fig. 9, in which a linear movement was used, this image shows no linear shadows which would interfere with image interpretation. In addition, this image clearly shows the entire configuration of bronchial and vascular structures, and is able to clearly visualize mediastinal lines such as the azygos, esophageal and paravertebral lines. In these cases, images were processed in auto mode (automatic setting of sensitivity and latitude). In this technique, the maximum and minimum values are determined based on analysis of a radiation dose (light emission) histogram of the imaging plate, and the sensitivity and latitude are set so that the range of the image signal corresponding to the level of light emission are contained within the limits of an 8-bit (0 to 255) digital image signal. The latitudes (L value) for data recording in cases (a) and (b) were 2.3 and 1.2, respectively. CR permits a wide dynamic range to be achieved, so an image of the entire mediastinal and hilar region can obtained with the proper density without the need to use a compensating filter. However, image quality is not yet entirely satisfactory. As can be seen in this case, since the differences in X-ray absorption between the mediastinum and the lung field are quite large the image must be obtained using a low gamma level. This relults in a low-contrast image. Furthermore, the mediastinum is adversely affected by scattering from the lung field, further reducing image contrast. However, it is well known that, in general, the higher the contrast, the higher the detectability. Use of compensating filter permitted differences in X-ray dose of the mediastinum and lung field on the imaging plate to be minimized, with consequent reduction in the range of maximum and minimum value on histogram. This resulted in sharper contrast and improved detectability in the mediastinal and hilar regions. When inferior density compensation (i.e., density variation) occurred at the border between the mediastinum and the lung field due to incorrect setting of the filter or due to the selection of a filter shape which poorly matched the cnfiguration of the particular mediastinum under examination, for example, in a mediastinum containing lesions, the authors were able to use CR to minimize density variation by gradation or frequency processing in order to obtain the appropriate contrast level for image reading. In addition, the authors employed auto mode processing to obtain images of the enitre mediastinal and hilar region with appropriate density for reading thorugh automatic setteing of gradient based on variation within the range of maximum and minimum values in the X-ray dose histogram in accordance with the degree of density variation.

The time factor is one of the most important factors in thoracic tomogaraphy because of the effects of the patient's respiratory movements, cardiac and aortic motion. In tomography, selecting the most suitable movement for the individual case or region is essential, because the movement selected limits exposure time. There are a large number of reports and clinical evaluations concerning this topic in the literatures[7)8)9)10)].

Fujii, et al., have developed a short-exposure linear tomographic unit and have reported on their findings[12)13)]. The exposure time of 0.6 seconds which was employed in this study is not as short as the exposure time of 0.5 seconds used by Fujii, et al. However, despite the fact that a circualr movement was used, the exposure time was the same as or shorter than that obtained when conventional linear movement exposure at $2\theta=40°$ is performed. For this reason, no blurring due to motion of the object were almost encountered and the image border were quite sharp. It is generally impossible to obtain two exposures in stereozonography for stereoscopic viewing due to changes in the patient's respiratory phase. Authors investigated this effect using a 5.0 mm stepped paper phantom with 1.0 mm-diameter wires spaced at 50 mm intervals, and concluded that a shift of less than 10 mm does not significantly interfere with image reading. In addition, authors found that the difference in chest thickness during normal and deep breathing in 50 cases was about 20 mm. Since the tomographic plane is set at the bifurcation of the tarachea, which is located at the center of the chest, the differences is about 10 mm. Thus, if the patient is carefully instructed concerning proper breathing techniques, this difference should not be a problem. Today, with many recent advances in thoracic surgery and radiotherapy, the accurate localization of mediastinal and hilar lesions is increasingly important. For patients with primary lung cancer in particular, accurate assesment of the clinical stage influences the prognosis and plays an important role in selecting the appropriate course of treatment. In this situation, clear images of the trachea, bronchial, blood vessels, lymph nodes, mediastinum, etc. are indispensable. Stereozonography promises to be extremely improtant in obtaining such clinical information.

5. Conclusion

1) Stereozonography based on the tomographic technique permits detailed stereoscopic visualization of complex, superimposed bronchial and vascular images in the mediastinal and hilar regions. This technique promises to be an effective means for examining these regions.

2) In contrast to linear movement tomography, circular movement tomography does not generate linear shadows which interfere with image interpretation. In addition, circular movement tomography permits accurate visualization of the entire configuration of bronchial and vascular structures. Further, it is able to clearly show mediastinal lines such as the azygos, esophageal, and paravertebral lines.

3) The short exposure time of 0.6 seconds almost completely eliminates blurring caused by movement of the object, so that the borders of structures are clearly displayed on the image.

4) Utilization of a compensating filter increases contrast and improves detectablility in the mediastinum and pulmonary hilum.

5) When a CR image suffers poor density compensation due to incorrect setting of the filter or the selection of a filter shape which is poorly matchd to the mediastinum under examination, CR permits density variations to be regulate through gradation and frequency processing to obtain optimal contrast for image interpretation.

6) Combined use of the compensating filter and CR permits free setting of the gamma level in accordance with an X-ray dose histogram corresponding to the dose ratio of the mediastinum and lung field. Therefore, contrast can be enhanced. In this regard, CR is considerably better than the conventional film techniques.

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