The 1st Dynamic Digital Radiography Seminar

Date and time : 14:00 to 17:30, Saturday, October 13, 2018

Venue : JP Tower 14F Konica Minolta Co., Ltd. bizhub SQUARE

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Dynamic Digital Radiography image that changes common sense in respiratory imaging

- A static image that captures the form and a dynamic image that reflects physiology

Shoji Kudoh, MD, PhD Chairman, Board of Directors, Japan Anti-Tuberculosis Association / Professor Emeritus, Nippon Medical School Foundation

In this lecture, based on the history of respiratory imaging, we will discuss the possibilities and expectations of Dynamic Digital Radiography (DDR) image that change the conventional wisdom.

History of respiratory diagnostics

The pioneers of respiratory diagnostics sought a way to know the internal condition of the lung without dissection, which led to the development of a percussion method in 1761 and the invention of a stethoscope in 1816 (**Fig. 1**). Although the chest image diagnosis starts with the discovery of the X-ray in 1895, it can be seen that it was widely spread in the 1920s, and the chest plain X-ray has played an important role in respiratory diagnosis.

Chest image diagnosis has evolved from simple chest radiographs to chest CTs and high resolution CTs, in response to the desire to see the morphology in more detail. High-resolution CT has made it possible to analyze the structure of the secondary lobule of the lung, and the resolution has been further improved.

It is the basic procedure of the history of respiratory imaging that has developed into high-resolution images that "reflect form."

Effects of gravity on the pulmonary circulation and static images

On the other hand, the chest X-ray also has an element that "reflects physiology". The lungs affected by gravity are less likely to be visible in blood vessels above the hilum of healthy subjects in standing X-ray exams, and this is explained using a model of hydrostatic pressure in a textbook written by J.B. West in 1962 [1] (**Fig. 2**).

In static images, for example, when congestive heart failure occurs, the ascending blood vessel becomes visible, and it is understood that information reflecting physiological information is also included.

Impression of DDR image

When I first got the introduction of dynamic chest X-ray image from Konica Minolta, it was of course naturally moving due to breathing, and I felt that I could catch the heartbeat and the movement of the diaphragm well (**Fig. 3**). And since it is a standing X-ray exams, the physiological information influenced by gravity is reflected, and an image in which the density changes

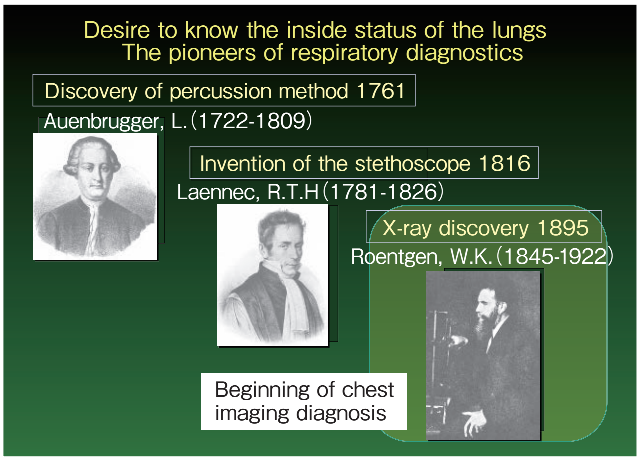

Fig. 1 History of respiratory diagnostics

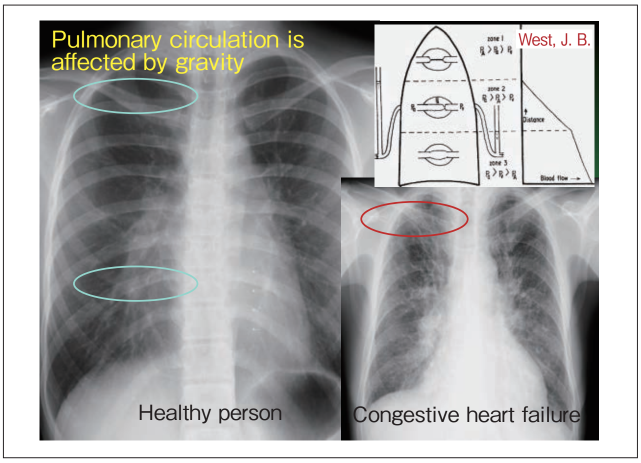

Fig. 2 Effect of gravity on the pulmonary circulation

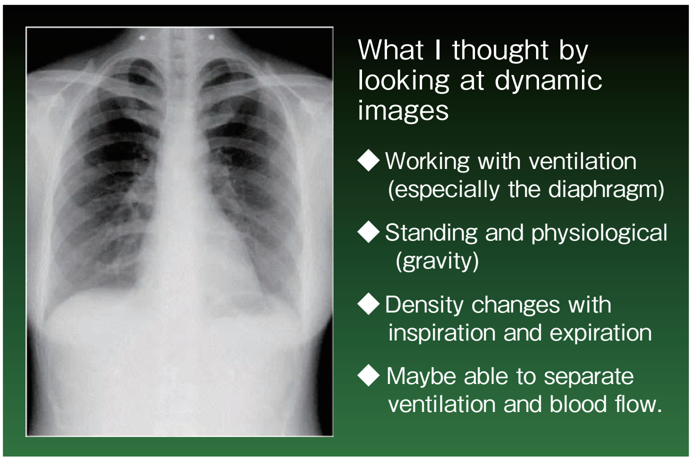

Fig. 3 Impression of DDR image

between inspiratory and expiratory can be obtained. Based on these characteristics, we thought that it might be possible to separate intake and blood flow.

The particular important thing in exhaled breath physiology is the physiology of gas exchange. The mapping of the "Ventilation Blood Flow Ratio measured by standing position ($\dot{V}_A/\dot{Q}_C$)" published in J.B. West's textbooks has been used for respiratory physiology over the past 55 years. It remains as a central dogma, but until now no one could verify it. However, it is considered that there is a possibility that this verification can be performed by the X-ray dynamic image.

Expectation to DDR image

The visualization of the movement of the diaphragm and thorax with DDR image is useful for measuring effects of respiratory rehabilitation and for diagnosing phrenic nerve palsy and chronic obstructive pulmonary disease (COPD) [2), 3)]. Besides, by observing blood flow distribution and ventilation distribution in a standing position, diagnosis of thrombotic pulmonary disease, local distribution abnormality of COPD, congestive heart failure, etc. will be possible [4)]. The DDR image is a technology originating in Japan, and I think that it is an area that Japan should lead at once in anticipation of the world now, as papers are starting to appear in Japan.

●References

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2) Yamada, Y., Ueyama, M., Abe, T., et al. : Time-Resolved Quantitative Analysis of the Diaphragms During Tidal Breathing in a Standing Position Using Dynamic Chest Radiography with a Flat Panel Detector System ("Dynamic X-Ray Phrenicography") ; Initial Experience in 172 Volunteers. *Acad. Radiol.*, 24 (4) : 393-400, 2017.
3) Hida, T., Yamada, Y., Ueyama, M., et al.: Decreased and slower diaphragmatic motion during forced breathing in severe COPD patients; Time-resolved quantitative analysis using dynamic chest radiography with a flat panel detector system. *Eur. J. Radiol.*, 112 : 28-36, 2019.
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Certificate of Merit

Dynamic Chest Radiography Using Flat Panel Detector System: Technique

Rie Tanaka, PhD College of Medical, Pharmaceutical, & Health Sciences, Kanazawa University

In this lecture, we will report on the technical features of Dynamic Digital Radiography (DDR) and results of our experiments on animal.

Technical features of DDR

DDR is a new diagnostic method for lung function by using low-dose [1]. Shoot for 10 seconds at 15 fps and acquire 150 frames of X-ray images. The difference from chest plain radiography is breathing. In addition, the exposure dose of DDR can be kept lower than the total dose of 1.9 mGy of two-directional plain chest radiography recommended by the International Atomic Energy Agency (IAEA). This is because technological advances in FPD have made it possible to perform imaging at lower doses than in the prior technology. Konica Minolta's FPD has high linearity between incident dose and output pixel value. By combining it with an X-ray generator emitting X-ray pulses of 3 to 15 fps, the DDR in a general imaging room becomes possible.

In DDR, the movement of the diaphragm, chest, ribs, heart wall, and changes in density in the lung field due to respiration and heart beat can be observed by moving images. The observation of the diaphragm movement by moving images enables evaluation of the range of movement, timing of movement, and left-right synchrony. Also, by measuring the distance from the apex of the lungs to the diaphragm for each frame, and graphing the movement amount and range of movement, movement timing, and synchrony etc., the detailed quantitative evaluation becomes possible.

Furthermore, it should be noted that, in chest radiography, the changes in pixel values in the lung field caused by differences in X-ray transparency can be in black and white shades. There are two patterns followed by changes in pixel value. One is density change of pulmonary blood vessels and bronchial volume per unit volume; and the lung field becomes white in exhalation and dark in inhalation. The other pattern is that the lung field is white during systole and dark during diastole due to changes in circulatory dynamics associated with heart beat. However, because it is difficult to evaluate these with the naked eye, the digital image processing is performed to create a color image that emphasizes on ventilation and blood flow.

Evaluation of DDR by animal experiments

We received financial support for medical expenses from the Utsukushima (Beautiful Fukushima) Next-Generation Medical Industry Agglomeration Project (2014-2016), and conducted experiments using pigs with the cooperation of Shiga Medical University and Fukushima Medical University. In this experiment, we examined two themes of ① drawing the increase and decrease of inspiratory volume by pixel value and expressing the amount of change by color intensity, ② artificially creating an atelectasis and delineating it as a defect in color.

By this experiment, with regard to ①, the pixel value is also increased according to the increase of inspiratory volume, and it can be expressed by color intensity, and high correlation between the inspiratory volume and change amount of pixel value was confirmed (**Fig. 1**). Also, when comparing the tidal volume between the normal model and the right lung atelectasis model, there is no significant difference between right and left lungs in the normal model, but in case of right lung atelectasis model, the pixel value of the right lung is significantly decreased and the pixel values of normal left lung is increased. This is considered to be because the tidal volume of the normal left lung has been increased to maintain function.

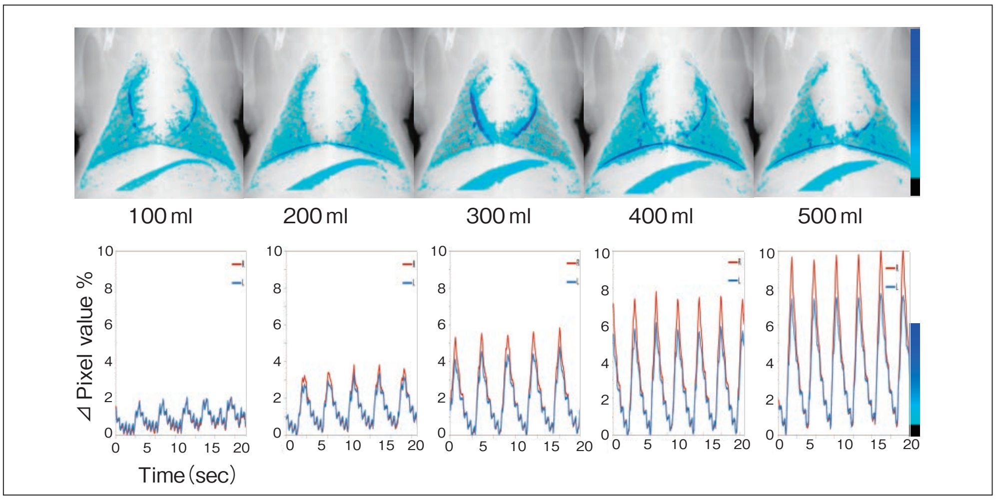

Fig. 1 Alveolar hypoventilation syndrome caused by right diaphragmatic nerve palsy

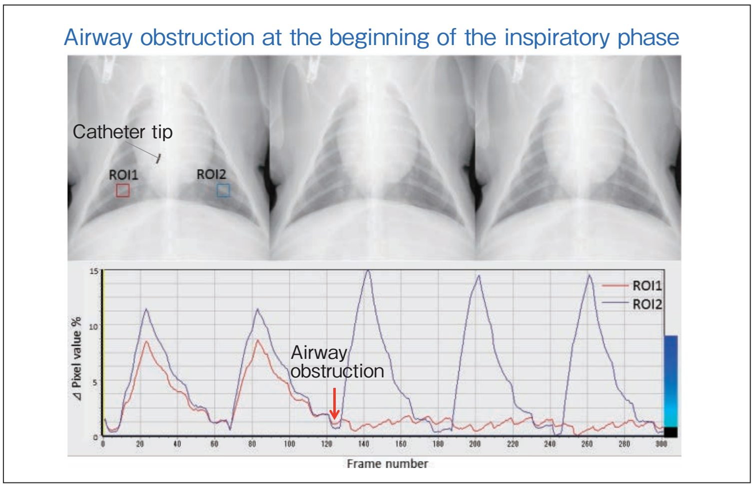

Fig. 2 Quantitative comparison of diaphragm movement

With regard to ②, we checked the pixel values in the early expiratory phase of normal left lung and right lung which was intentionally airway-obstructed using a catheter. It has been confirmed that the pixel value of the normal left lung was increased and the pixel value of the obstructed right lung was decreased and became flat **(Fig. 2)**. In addition, when airway obstruction was performed in the initial exhalation phase immediately after inspiration, the pixel values of obstructed right lung became flat while maintaining high values, and it was considered that air trapping occurred. Furthermore, in the atelectasis model, it is also confirmed that the pixel value increased with each exhalation. It seems that this is capturing hyperinflation in the lung field, and we got a result that DDR can also visualize air trapping. We also examined each lung lobe with atelectasis model, we were able to visualize the decrease and loss of color intensity at the atelectasis part.

These examinations revealed that DDR can be used to make a relative assessment of the inspiratory volume and detect lung ventilatory impairment on a per lobe basis. In addition, it is thought that differential diagnosis of air trapping and air flow restriction can also be performed, and it has been shown that a minimally invasive lung function diagnosis can be realized in a general X-ray room without using a contrast medium. Besides, we also examined the possibility of pulmonary blood flow analysis and changed the pixel value according to the blood flow, and were able to perform color mapping.

Future outlook

It is important to keep in mind that DDR does not depict lung ventilation at the alveolar level, but rather depicts relative lung functions such as changes in lung blood vessel and bronchial density. However, the DDR can be said to be a new lung function diagnostic technology that has the possibility of dramatically increasing the diagnostic information obtained in general X-ray rooms, “from static to dynamic, from form to function”.

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Magna Cum Laude

Dynamic Chest Radiography Using Flat Panel Detector System: Clinical Usefulness

Yoshitake Yamada, MD, PhD Department of Diagnostic Radiology, Keio University School of Medicine

This lecture reports on evaluation of diaphragm movement, ventilation weighted image and blood flow enhanced image by using Dynamic Digital Radiography (DDR).

Evaluation of diaphragm movement

Since the DDR is continuous image data, in addition to the distance of the movement of the diaphragm, the speed of movement of the diaphragm can be evaluated by performing differentiation (**Fig. 1**). In this study of healthy volunteers, the diaphragm movement under resting breathing in 172 volunteers (Japanese) averaged 11 mm in the right diaphragm and 15 mm in the left diaphragm, and the left diaphragm moved significantly more than the right diaphragm. In multivariate analysis, the higher value of both BMI and tidal volume, the greater movement of the diaphragm. Furthermore, in comparison of diaphragm movements between 47 normal subjects and 39 chronic obstructive pulmonary disease (COPD) patients, COPD patients moved significantly more under rest breathing. In previous studies under forced breathing, COPD patients had smaller movements, but the result was opposite. In addition, the multivariate analysis also revealed to be higher BMI in COPD patients, greater movement of the diaphragm under resting breathing [1]. This seems to be moving the diaphragm significantly to compensate for the decline in gas exchange function in COPD patients

We also evaluated the diaphragmatic movements of healthy and COPD patients under forced breathing. When dividing into mild (grade 1/2) and severe (grade 3/4) according to GOLD classification, patients with grade 3/4 have significantly smaller diaphragmatic movements under forced respiration than normal subjects and grade 1/2 patients.

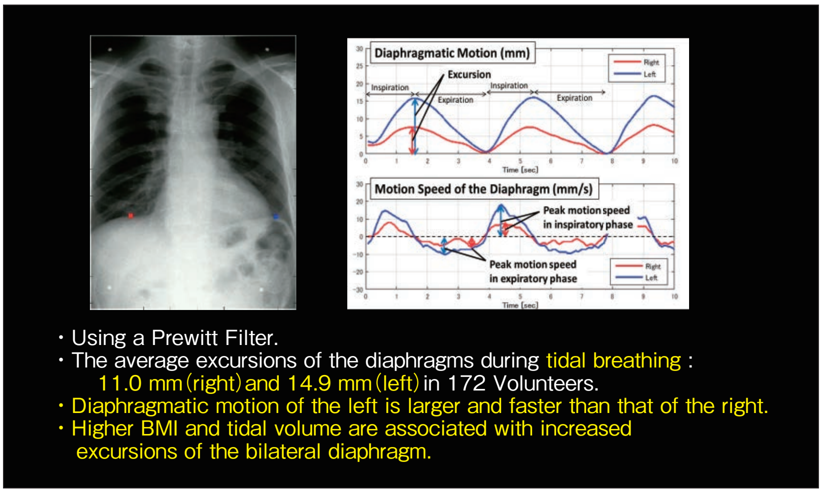

Fig. 1 Evaluation of diaphragmatic movement by DDR image

Ventilation emphasis image

Lung pixel values change with respiration and cardiac output. By using a low-pass filter and a high-pass filter in DDR, it is possible to visualize the change of X-ray permeability by ventilation with pixel values and create a ventilation emphasis image. The ventilation emphasis image is displayed in green where the pixel value decreases with inhalation and in orange where the pixel value increases during exhalation. When comparing the ventilation emphasis images of normal and COPD patients, the green and orange colors change uniformly in normal subjects, and the green and orange colors change in COPD patients unevenly. In the cases of following right lung cancer resection and radiotherapy in **Fig. 2**, the ventilation emphasis

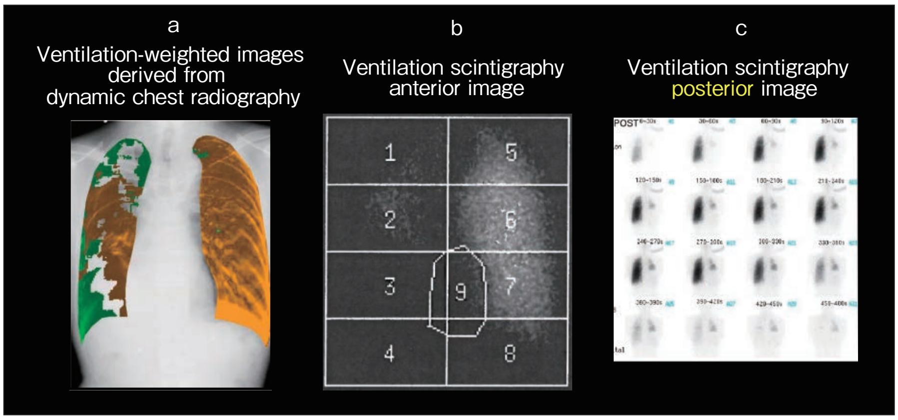

Fig. 2 Right lung cancer after resection and radiotherapy (68 years old, male)
a: Ventilation weighted image b, c: Lung ventilation scintigraphic image

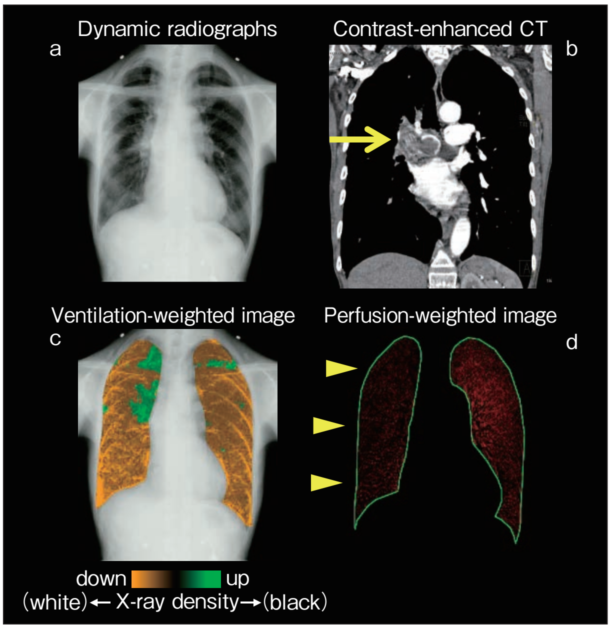

Fig. 3 Right pulmonary artery thromboembolism (75 years old, female)
a: Dynamic X-ray analysis image
b: Contrast-enhanced CT image
c: Ventilation emphasis image
d: Blood flow emphasis image

image **(Fig. 2a)** has the bulla portion of the right lung moving in reverse to the normal portion. Also in lung ventilation scintigraphy **(Fig. 2b, c)**, the uptake of nuclide was observed only in the normal part of the right lung, which was consistent with the ventilation emphasis image.

Blood flow emphasis image

Furthermore, by using the low-pass filter and the high-pass filter, it is possible to extract changes in pixel values of the lung due to heart beats, and to create a blood flow emphasis image. **Fig. 3** is a case of right pulmonary artery thromboembolism, and in the ventilation emphasis image **(Fig. 3c)**, the green shading indicates inspiration and orange shading indicates expiration, and both are uniformly distributed. Both lungs are believed to uniformly distribute air inspired. On the other hand, in the blood flow emphasis image **(Fig. 3d)**, the left lung showed a change consistent with heart-beat, but was not observed in the right lung. In the DDR image **(Fig. 3a)**, only the left lung changed pixel values in accordance with the heart-beat, and no change was observed in the right lung. From this, it can be said that changes in pixel values are accurately extracted to some extent in both the ventilation emphasis image and the blood flow emphasis image.

Summary

DDR has the advantage that ventilation and heart beat can be evaluated in the standing or sitting position. In our study, the left diaphragm moved more than the right diaphragm under resting and forced breathings, and higher than BMI, and larger than the movement of the diaphragm under resting breathing. Furthermore, in comparison with normal subjects and COPD patients, the movement of the diaphragm was greater in normal subjects under forced respiration and in COPD patients under rest breathing. In addition, in ventilation emphasis images, differences were seen in changes in pixel values due to ventilation in healthy subjects and COPD patients. On the other hand, the blood flow emphasis image is expected to allow assessment of coarse pulmonary artery thromboembolism without the use of contrast agents.

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1) Yamada, Y., Ueyama, M., Abe, T., et al. : Difference in diaphragmatic motion during tidal breathing in a standing position between COPD patients and normal subjects ; Timeresolved quantitative evaluation using dynamic chest radiography with flat panel detector system ("dynamic X-ray phrenicography") . *Eur. J. Radiol.*, 87 : 76-82, 2017.

Progress of Dynamic Digital Radiography in our hospital

Fumio Sakamaki, MD Department of Respiratory Medicine, Tokai University Hachioji Hospital / Respiratory Division, Department of Internal Medicine, Tokai University School of Medicine

In our hospital, we have been conducting clinical research on medical treatment of respiratory diseases by Dynamic Digital Radiography (DDR) using Konica Minolta's FPD system from 2018. In this lecture, we outline the clinical research performed at our hospital while presenting actual cases.

Means and problems of respiratory disease medical treatment

In the severe cases of chronic progressive lung disease [such as chronic obstructive pulmonary disease (COPD) and interstitial pneumonia] among respiratory diseases, in recent years, shortness of breath evaluation by a medical interview [corrected MRC (mMRC), COPD assessment Test (CAT) score] and the number of acute exacerbations (exacerbation risk) are very important. In addition, the imaging diagnostics such as plain radiography, CT, pathological examination, and the functional examination such as ventilation function assessment, lung volume fractionation (residual mass), diffusion ability (DLco), and biochemical examination indicative of pathology are assessed using index values, and it can be seen that the prognosis differs greatly even in similar cases of COPD and idiopathic pulmonary fibrosis (IPF).
For example, in COPD, in the new GOLD classification revised in 2011, it is classified into four of A to D in consideration of mMRC, CAT score, exacerbation risk, etc. in the conventional staging (stage 1-4). In such cases, it is recommended to change the treatment approach. The exacerbation of COPD is likely to occur in specific patients [1], but the issue is how to extract it.

Clinical research practice in our hospital

Thus, we think that we may be able to extract cases with high severity and risk of exacerbation by performing analysis by taking chest X-ray dynamic images at the first examination at our hospital, and we initiated clinical research from January 2018. The subjects are normal control approximately 10-20 cases, COPD approximately 20-30 cases, pulmonary emphysema and pulmonary fibrosis (CPFE) approximately 5-10 cases, and other diseases approximately 20 cases. Clinical data include symptom records (mMRC, CAT score, number of exacerbations/year), oxygen saturation (SpO_2), lung function (as far as possible to DLco), plain radiograph, CT (with high definition CT) and so on.

1. Process flow for system configuration and tests in our hospital

In our hospital, we use the Konica Minolta DDR system to shoot for approximately 10 seconds in the shooting room, and save the static image in PACS, and transfer the movie to a dedicated movie analysis workstation to perform motion analysis. The usefulness of this system is that the exposure dose is as small as several plain radiographs and that imaging is easy. Findings similar to CT can be obtained with simpler and lower dose than CT.

2. Outline of previous cases

The breakdown of cases in which chest dynamic analysis was performed until September 2018 is as follows: COPD (the largest group): 19 cases, interstitial pneumonia: 8 cases, pulmonary thromboembolism: 9 cases, lung cancer: 1 case, other conditions: 5 cases. Among these cases, COPD was most frequently stage 2 and least frequently stage 3 as a result of evaluating severity using the conventional GOLD classification from 1-second dose vs. predicted value (% FEV1) of spirometry. On the

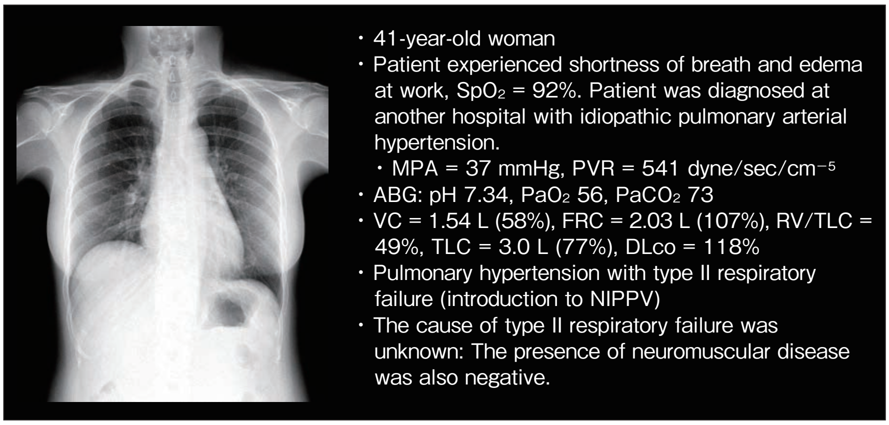

Fig. 1 Alveolar hypoventilation syndrome due to right diaphragmatic nerve palsy

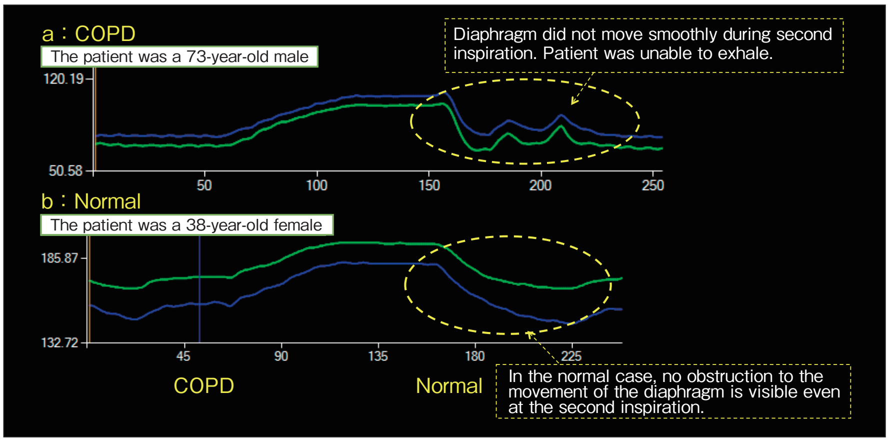

Fig. 2. Quantitative comparison of diaphragm movement

other hand, when the same case was evaluated by the new GOLD classification (A to D) in consideration of the exacerbation risk, B was the largest even in the same four stages, and A, C, and D were almost the same. In other words, it was found that, among the same %FEV1 cases, those with a high risk of exacerbation were included.

3. Case presentation

Fig. 1 : The patient was a 41-year-old female. The patient was diagnosed with idiopathic pulmonary arterial hypertension (PAH) at another hospital because of shortness of breath, edema, and hypoxemia, and visited our hospital. In lung function test, the lung capacity decreases with 58%, and the functional residual capacity (FRC) increases with 107%, but the total lung capacity (TLC) is small with 77%, while DLco is normal with 118%, and the lung parenchyma was considered not to be impaired. Chest dynamic imaging revealed respiratory failure due to right diaphragmatic nerve palsy that was not known in the static image, and was diagnosed with alveolar hypoventilation syndrome.

In addition, in severe COPD cases, the regions with less change during exhalation and inhalation are observed in chest dynamic imaging compared to normal lungs, and its quantification is required in the future.

In addition, our hospital is also conducting research to compare the movement of the diaphragm of cases with different respiratory functions quantitatively. When COPD and normal cases are compared, no disorder is found in the movement of the diaphragm in healthy cases (**Fig. 2b**), but in COPD, the movement of the diaphragm is irregular at the second inhalation (**Fig. 2a**).

Expectations for chest dynamic imaging

Chest dynamic imaging is expected to make it possible to observe chest movement, collapse of the central airway, imbalance of ventilation, and assessment of severity and exacerbation risk in COPD and ventilatory failure. This is believed to be useful in the assessment of the severity and exacerbation risk of interstitial lung disease, and early diagnosis of pulmonary circulatory disorders in emergency outpatients. In addition, since this method can also be expected to be able to remove the overlap between tumor and bone, which is a weakness of ordinary chest radiographs, it is expected to be effective as a screening for neoplastic lesions in the future.

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Examination of evaluation method of respiratory function by Dynamic Digital Radiography image

Noriyuki Ohkura, MD Department of Respiratory Medicine, Kanazawa University Hospital

At our hospital, we used a Konica Minolta Dynamic Digital Radiography (DDR) system to examine respiratory function. In this lecture, we will discuss actual examination method and its results.

Purpose and methods

The purpose of this study was to verify the relationship between lung area change and respiratory function by comparison with lung volume fractionation, maximal effort calling curve, and COPD assessment test (CAT) score. In this way, we aim at establishment of respiratory function test with little burden on patients, construction of alternative method of precision lung function test, evaluation of physical activity.

The method is the examination of chest X-ray movie and respiratory function in 121 subjects (80 males, 41 females, age range: 68.5 ± 9.3 years), and the rate of change in pulmonary area (% Change) due to respiratory change is (maximum inspiratory lung area-maximum exhaled lung area) / maximum inspiratory lung area. The breakdown of cases was as follows: lung cancer in the normal spirometric range: 36 cases, COPD: 46 suspected cases and 7 confirmed cases, interstitial pneumonia: 24 cases, asthma: 3 cases, other conditions: 5 cases. The imaging system is almost the same as the conventional static image shooting except for pulse irradiation, and performs shooting for 15 frames over a period of 10-20 seconds from deep exhalation to deep inspiration. The exposure dose is equivalent (0.23mSv) to the front + side view of a still image even with a 20-second exposure.

Evaluation and Discussion

The subject was relatively elderly and approximately a half of them had some form of air flow restriction, and as such the 1-second rate (FEV_1 / FVC%) tended to be low at 70%. Looking at the correlation between lung area and respiratory function at the maximum inspiratory position (**Fig. 1**), vital capacity (VC), functional residual capacity (FRC), total lung capacity (TLC), etc. A

Correlation between lung area (maximum inspiratory position) and respiratory function (n = 121)

	Lung area r	Lung area p
VC	0.72	< 0.05
FEV_1	0.53	< 0.05
FEV_1/FVC	−0.33	< 0.05
MMF	0.004	0.96
FRC	0.86	< 0.05
RV	0.69	< 0.05
RV/TLC	0.001	0.99
TLC	0.82	< 0.05

Lung area (maximum inspiratory position) was positively correlated with vital capacity, functional residual capacity, and total lung capacity.

Fig. 1 Correlation between lung area and respiratory function at maximum inspiratory position

Correlation between rate of change in pulmonary area and respiratory function (n = 121)

	%Change r	%Change p
VC	0.21	<0.05
FEV_1	0.31	<0.05
FEV_1/FVC	0.05	0.61
MMF	0.15	0.11
FRC	−0.10	0.28
RV	−0.18	<0.05
RV/TLC	−0.40	<0.05
TLC	0.07	0.46

The rate of change in lung area is
- vital capacity, 1 second volume and a weak positive correlation were observed.
- A negative correlation was found between and residual rate.

Fig. 2 Correlation between rate of change in pulmonary area and respiratory function due to respiratory fluctuation

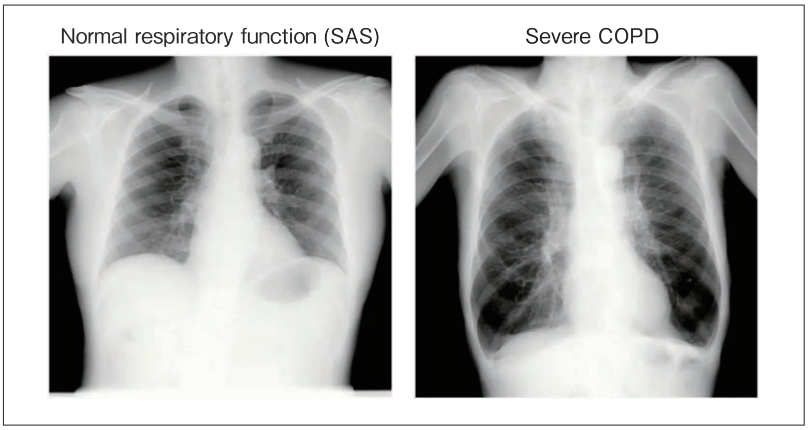


Fig. 3 Image comparison of normal respiratory function (sleep apnea syndrome) and severe COPD

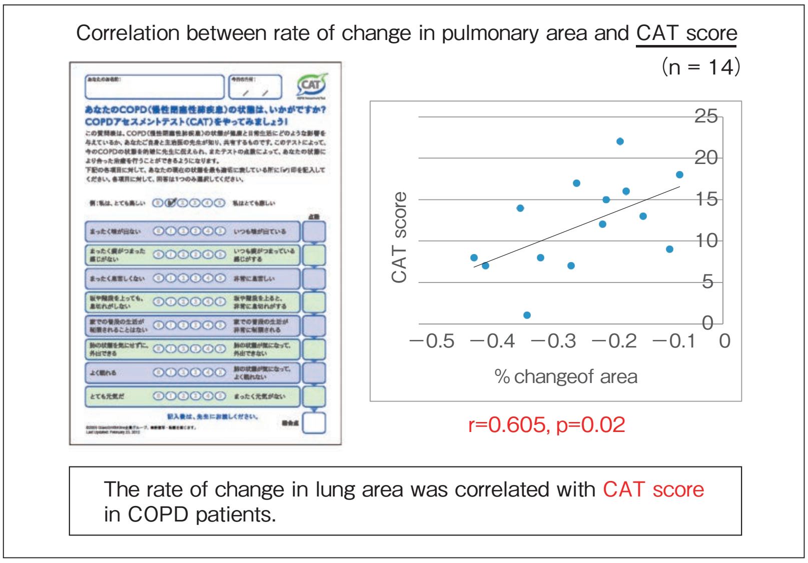


Fig. 4 Correlation between rate of change in pulmonary area and CAT score in COPD

positive correlation was found, but no correlation was found between the 1-second volume (FEV_1) obtained from the forced expiratory curve, the 1-second rate, and the maximum expiratory flow rate (MMF). Next, looking at the correlation between lung area change rate and respiratory function with respiratory fluctuation (**Fig. 2**), vital capacity and 1 second dose were weakly positively correlated, and residual rate (RV/TLC) was negatively correlated. In particular, the correlation with the residual rate suggests that the lung movement may deteriorate as hyperinflation progresses.

Furthermore, since obstructive ventilatory impairment and restrictive ventilatory impairment were mixed in this subject, the analysis was first limited to cases with airflow restriction (obstructive ventilatory impairment). When the stratification and rate of change in pulmonary area were divided according to the predicted value within one second, the rate of change in pulmonary area decreased with the progress of airflow limitation, and the lung movement was worse as the obstructive ventilatory impairment progressed. Next, when restrictive ventilation disorder (interstitial pneumonia) cases were stratified for each vital capacity and examined, the rate of change in pulmonary area decreased as vital capacity decline progressed, and the movement of the lungs was worse as the lungs shrank. These findings suggest that quantification of lung area change may be useful for evaluating the progression of COPD and interstitial pneumonia. In fact, when DDR were used to compare normal respiratory function (sleep apnea syndrome : SAS) with severe COPD, it was confirmed that the lungs were hyperinflated and movement was poor in severe COPD cases (**Fig. 3**).

Thus, QOL was also evaluated in the COPD cases. The CAT score, which is widely used in clinical practice, is an evaluation method that scores eight questions related to QOL, such as cough, sputum, dyspnea, activity, and depression tendency. The higher the score, the stronger the symptoms. On the other hand, the rate of change in pulmonary area decreased as the symptoms became stronger, and showed a correlation with the CAT score (**Fig. 4**). In other words, it is shown that lung motion was not only correlated with respiratory function but also with QOL evaluation.

Result

The lung area was strongly correlated with the lung volume fraction. The rate of change in pulmonary area associated with respiratory fluctuation was correlated with the residual air rate and decreased with the progress of airflow restriction and decreased vital capacity, and in COPD patients, the correlation with CAT score was also observed. From the above, DDR image is expected to be used as substitutes for respiratory function test with low patient burden and physical activity evaluation.

Practical use of Dynamic Digital Radiography (DDR) in lung resection

Masaya Tamura, MD Department of Thoracic, Cardiovascular and General Surgery, Kanazawa University

At our hospital, we perform pulmonary resection for lung cancer. We considered that Dynamic Digital Radiography (DDR) would be useful in the perioperative period, and ① examined non-invasive respiratory function evaluation method for pulmonary resection case, and ② examined the application of DDR in pulmonary resections.

Examination of respiratory function evaluation for pulmonary resection case

In 58 patients who underwent lobectomy for lung cancer between February 2016 and December 2017, rate of change in pulmonary area was examined using DDR. Background: Case breakdown: normal lungs: 21 cases, emphysema complicated by fibrosis: 10 cases, pulmonary fibrosis: 7 cases, pulmonary emphysema: 20 cases. The resected lobes were located in the upper lobe in 33 cases and in the lower lobe in 25 cases. Postoperative complications were seen in 11 cases: 5 cases of pneumonia, 1 case of acute exacerbation of interstitial pneumonia, and in 5 cases of air leakage.

The radiographs were taken before surgery, one week after surgery, and one month after surgery. The verification method compares the lung area change rate of the affected side lung for each group for the presence or absence of preoperative background lung, resected leaves, and postoperative complications. The rate of change in pulmonary area is calculated by the formula [(maximum inspiratory lung area– maximum expiratory lung area)/ maximum expiratory lung area].

1. Comparison of preoperative background lung

Comparison of rate of change in pulmonary area of lung in the preoperative background with normal lung, emphysema complicated fibrosis, pulmonary fibrosis and pulmonary emphysema. Although there is no significant difference, patients with pulmonary fibrosis were preoperatively compared with normal lungs, and the rate of change in lung area tended to be lower in these patients ($p = 0.07$).

2. Comparison of resected pulmonary lobes

Comparison of rate of change in pulmonary areas between upper and lower lobectomy groups showed no particular tendency before surgery, but when the upper lobectomy group was compared to the lower lobectomy group 1 week after surgery, the rate of change in lung area tended to be lower in these patients ($p = 0.07$). Comparing X-ray dynamic images of upper lobectomy case and lower lobectomy case, it can be seen that, in the lower lobectomy case, the movement of the blood vessel shadow and diaphragm is large overall and the rate of change in pulmonary area is high, but in the upper lobectomy case, there was a tendency for the movement of the affected side to be small. After one month, there was almost no difference in rate of change in pulmonary areas in both groups.

3. Comparison of postoperative complications

Comparison of rate of change in pulmonary area before surgery for the group [complication (+)] and the group [complication (-)] not showing postoperative complications, complications (+) tended to be slightly lower than complications (-) ($p = 0.09$). In addition, complications (+) were significantly lower at one week after surgery ($p = 0.04$). The possibility that the influence of the insertion of a drain may have an effect on patients with air leakage cannot be ruled out, but in comparison with the presence or absence of postoperative complications, there is a tendency for the rate of lung area

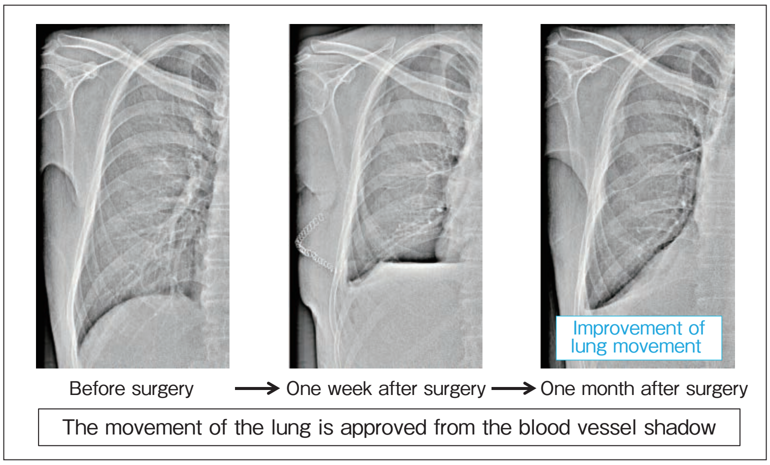


Fig. 1 Follow-up observation after pulmonary resection

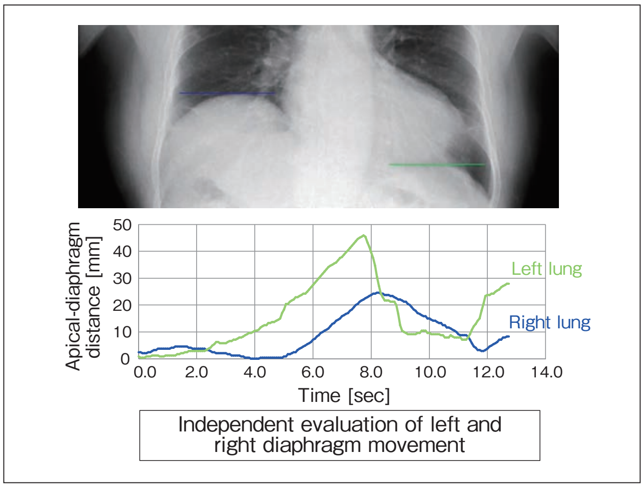


Fig. 2 Confirmation of diaphragmatic nerve palsy

change to decrease with complications (+). It can be said that.

4. Summary

Background: In the comparison of lung, patients with pulmonary fibrosis tended to have a lower rate of change in lung area before surgery. In addition, in comparison of resected leaves, patients who received upper lobe resection usually tended to have a decrease in rate of change in pulmonary area for one week after surgery. There was also tendency for the rate of change in pulmonary area before operation to decrease and the rate of change in pulmonary area for one week after the operation was significantly lower than those with no postoperative complications.

These findings suggest that DDR may be able to evaluate lung function before and after pulmonary resection and may contribute to postoperative complication prediction.

Examination of utilization method of DDR in pulmonary resection case

The possibility of using DDR in pulmonary resection is explained based on actual case images.

In the dynamic image, the movement of the lung can be visually observed from the blood vessel shadow, and it is thought that it can be used for follow-up observation after surgery. **Fig. 1** is a (dynamic) image of the patient who underwent resection of the right lung before surgery, one week after surgery, and one month after surgery. One week after surgery, the lungs were still affected by withdrawal and respiratory motion was poor, but after one month, we found that this motion had improved.

DDR can be used for quantitative analysis. By measuring the distance between the lung apex and the diaphragm, the movement of the left and right lungs and diaphragm can be evaluated separately. In the case of diaphragmatic nerve palsy, quantitative evaluation clearly shows that the movement of the right diaphragm is less than that of the left, and that the left-right synchrony is lost (**Fig. 2**). Such a left-right difference is information that is difficult to grasp in a still image, and is an area where DDR image can be used.

In addition, DDR can be used to confirm adhesions and infiltration. Dynamic images that allow visual observation of blood vessel shadows and chest wall motions can easily estimate adhesion sites where movement is restricted and infiltration sites, and are useful for preoperative and postoperative evaluation of pulmonary resection.

Summary

DDR is very useful in postoperative follow-up, detection of diaphragmatic nerve palsy, detection of adhesions, detection of chest wall invasion and aortic invasion, etc., and may be used in the perioperative period of pulmonary resection.

Evaluation of surgical indication by Dynamic Digital Radiography

Jun Hanaoka, MD, PhD Division of General Thoracic Surgery, Department of Surgery, Shiga University of Medical Science

We perform approximately 230 operations a year in our hospital, of which around 120 are pulmonary resection for primary lung cancer. During the perioperative period of pulmonary resection, respiratory function evaluation has been performed by spirometry, but early examination after the operation may not have been able to be measured sufficiently due to wound pain. In addition, at our hospital, evaluation was performed by CT volumemetry before, but it was not possible to evaluate it dynamically because it was taken under maximum breath respiratory arrest.

Dynamic Digital Radiography (DDR) that enables dynamic evaluation is considered to be able to evaluate how the lungs are changing during forced breathing and at rest breathing, and after approval by our ethics committee, clinical imaging started in June 2018. In this lecture, we introduce DDR research in our hospital.

Evaluation of respiratory function in pulmonary resection

DDR can visualize and quantify ventilation and blood flow information, but in our hospital, we focused on blood flow and decided to study its application in respiratory surgery.

With regard to the validity of dynamic X-ray analysis, it is reported that the correlation signal value and blood flow scintigraphy (^{99m}Tc), which represent blood flow and ventilation, were observed from Fukujuuji Hospital (R = 0.72) [1], and it has been shown that kinetic blood flow evaluation can substitute lung blood flow scintigraphy.

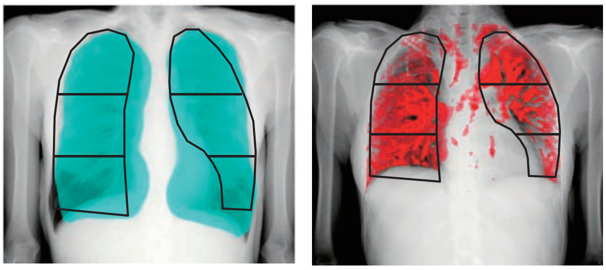
Preoperative risk assessment is important for highly invasive pulmonary resection. In particular, cardiopulmonary function is emphasized, and the “lung cancer medical care guideline” recommends that spirometry-based respiratory function evaluation be performed in the determination of surgical indication.

In respiratory function evaluation, measurement of vital capacity (VC) and 1 second rate (%FEV1.0) by spirometry, measurement of lung diffusion ability (DL_{CO}) in precision lung function test, calculation risk assessment is performed, such as postoperative respiratory function prediction. In postoperative respiratory function prediction, if the % FEV1.0 after surgery is less than 40%, there is a very high risk, so reduction surgery is considered.

Postoperative respiratory function prediction is to calculate the postoperative respiratory function using a formula based on the size of the remaining lung after resection and the respiratory function before operation. The lungs are divided into the upper lung, the middle lobe, and the lower lobe, and the left lung, the upper lobe and the lower lobe. The blood flow and the airway are divided into 19 anatomical areas. For example, if there is a tumor in the right upper lobe and resection of the right upper lobe (3 areas) is performed, the lung volume after resection is reduced by 16%, so lung function (%FEV1.0) is 100% to 84% before surgery I think it will decline. By multiplying this with the result of the respiratory function before operation, the postoperative prediction value is calculated.

Although this method is very simple, if you have chronic obstructive pulmonary disease (COPD) or interstitial pneumonia, the lung function has already decreased, so the present method of simply calculating based on the number of areas has low predictive accuracy. Thus, we perform lung blood flow scintigraphy in order to evaluate in

<New method>
Dynamic analysis



$$\text{post-operative } FEV1 = \text{pre-operative } FEV1 \times \left(1 - \text{contribution rate on the diseased side} \times \frac{\text{number of resected area}}{\text{number of affected area}}\right)$$

【merit】
Dynamic imaging with high predictive accuracy requires less effort and cost, and can be examined quickly to consider the state of blood flow and ventilation for each lung

Fig. 1 Postoperative respiratory function prediction by dynamic analysis

more detail at our hospital, calculate the postoperative respiratory function prediction value by considering the contribution rate on the affected side, and decide the appropriate treatment approach. However, lung blood flow scintigraphy test is time-consuming and costly, and the examination date is limited at our hospital, and the lack of urgency is an issue.

Postoperative respiratory function prediction by DDR

Therefore, we focused on postoperative respiratory function prediction and decided to examine the possibility of using DDR (**Fig. 1**). Dynamic analysis does not allow detailed evaluation of lung lobes and areas, but it is considered possible to evaluate left and right lungs separately. Dynamic analysis is expected to have high predictive accuracy because it accounts for the state of blood flow and ventilation for each of the left and right lungs. In addition, Dynamic radiography requires less effort and cost, and enables quick examination.

We are planning to carry out two confirmatory studies in the future. The first will be a comparison of postoperative respiratory function predictions with actual measurements. We will verify which method is appropriate by comparing the predicted values of postoperative respiratory function calculated from the calculation methods of the conventional method and kinetic analysis with the measured values of respiratory function measured after the operation. The second will be a comparison based on the presence of complications. We will compare the groups where post-operative complications occurred and the group where no complications occurred, and verify whether there is a significant difference in postoperative respiratory function prediction value. At the same time, we plan to examine factors related to complications from the animation and analysis results.

In addition, the imaging time is implemented at the timing of one month, three months, six months, and twelve months before surgery, postoperatively. Lung function is said to recover to the predicted value in 3 to 6 months after surgery, and we will consider including the course of the recovery.

Future outlook

As a future perspective of DDR, it is thought first that local abnormality evaluation of lung function could be performed. Since it is said that the respiratory function is reduced and cause complications if there is pulmonary emphysema or similar conditions in remaining lung tissue during pulmonary resection, we expect that our findings will be useful in connection with dynamic analysis to accurately estimate surgical risk.

The other is an evaluation of oxygenated blood flow ratio (V/Q) mismatch, and it is expected that evaluation will be possible by DDR with less labor, cost, and exposure, so we will examin the method.

●References

1) Aoki, M., et al : Dynamic Chest X-Ray Examination For Pulmonary Blood Flow Function: In Comparison With Tc-99m MAA Scintigraphy. American Thoracic Society 2012.

Clinical value and potential of Dynamic Digital Radiography
- From each specialized area

Chairpersons
Atsuko Kurosaki, MD, PhD Department of Diagnostic Radiology, Fukujuji Hospital, Japan Anti-Tuberculosis Association
Terumitsu Hasebe, MD, PhD Tokai University School of Medicine

Commentators
Yoko Shibata, MD, PhD Department of Pulmonary Medicine, Fukushima Medical University
Mitsuru Tabusadani, PhD Department of Respiratory Care and Rehabilitation, Fukujuji Hospital, Japan Anti-Tuberculosis Association
Hiromi Oda, MD, PhD Director of Saitama Medical University Hospital

In the 4th part of the discussion, we had active discussion after 4 commentators commented the clinical values and potential regarding the clinical application of Dynamic Digital Radiography (DDR) images in each specialization area under the title "Clinical value and potential of Dynamic Digital Radiography-From each specialized area".

Respiratory medicine
Possibility of replacing lung ventilation scintigraphy

Mr. Shibata: In the field of respiratory medicine, it is important to evaluate the imbalance of ventilation/blood flow ratio (V/Q mismatch) that causes hypoxemia. Conventionally, lung ventilation scintigraphy has been used as an evaluation method, but its spread has not progressed because of complicated inspection procedures, exposure, and high cost. However, the appearance of DDR images may facilitate the evaluation of V/Q mismatch. This is what many respiratory physicians have longed for, and we have great hope for future indications.

For example, chronic respiratory diseases may be exacerbated by respiratory tract infections etc., but the difference between stable respiration and dyspnea has not yet been clarified. It is thought that it is possible to evaluate what influence V/Q mismatch has on the pathological condition of chronic respiratory diseases by using DDR images. For this purpose, it is important in the future to consider a highly quantitative evaluation method.

Rehabilitation, emergency and disaster medicine
Expectation for use in respiratory rehabilitative guidance

Mr. Tabusadani: In our hospital, we have been teaching abdominal breathing, which is an efficient breathing method in the rehabilitation of patients with respiratory disease. There is a patient who can start to sit and stand from a supine position, but cannot perform abdominal breathing while in a standing position. It is considered that DDR images can be used in such cases to verify the patient's respiratory status and effective teaching methods.

In addition, DDR images may be useful for verifying the effectiveness of mouth-to-mouth breathing for the prevention of airway obstruction at the time of expiration conducted by patients with asthma or COPD. It is expected that it will become possible to observe in a moving image that "air-wrapping" is eliminated by whistling breathing. In addition, although instruction is given on inhalation for inhaled drugs such as bronchodilators, there are a large number of patients who cannot perform inhalation correctly, so if the dilation of the trachea and air flow by inhaling bronchodilators can be confirmed visually by DDR images, I thought it would be useful for confirming the effectiveness of inhalation instruction.

Apart from respiratory organs, the indications for rehabilitation of swallowing are expected. Although swallowing imaging (VF) is useful for assessment of dysphagia, DDR

may be useful as an alternative examination in facilities that are not well equipped and cannot be implemented in this technique. In addition, in rehabilitation in the field of orthopedic surgery, the adaptation to evaluation of joint movement can be considered.

On the other hand, the usefulness of DDR images is also expected in emergency care and super acute care environments such as the ICU. We are performing postural drainage in patients with lower lung injury, but it is important to accumulate information such as the location of atelectasis in the lung which is responsible for blood flow decline or respiratory failure. At present, CT is performed, but it is becoming possible to assess more easily by using DDR, and the improvement of treatment accuracy can also be expected in the future.

Orthopedics

Possibility to preoperative evaluation of total knee arthroplasty

Mr. Oda: The indications for DDR images in the field of orthopedics include the preoperative evaluation of total knee arthroplasty. Types include cruciate retention-type (CR-type) which preserves the posterior cruciate ligament and posterior stabilizer-type (PS-type) which involves placement of knee prosthesis. Although the CR type has no limitation on the maximum bending angle and can maintain its inherent deep area perception, it needs to peel off the attached part, thus making the procedure difficult. It is possible to increase the indication of CR type surgery and improve the accuracy of the procedure by evaluating the length of this affixation section exfoliation by using DDR image before surgery.

In addition, indications for lumbar spinal stenosis can also be expected. At present, myelography is performed in patients who have surgery indication, but it is possible to evaluate the indication of surgery etc., by observing the movement with DDR image.

The 1st
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The 2nd Dynamic Digital Radiography Seminar

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Date and time : 14:00 to 17:30, Saturday, November 2, 2019
Venue : Fukuracia Yaesu Conference Room A

CONTENTS

KONICA MINOLTA JAPAN, INC.

Evaluation of pulmonary circulation by Dynamic Digital Radiography: Comparison with pulmonary perfusion scintigraphy

Munehisa Takata, MD Department of Thoracic Surgery, Kanazawa University

We have been examining the evaluation of pulmonary circulation using a Dynamic Digital Radiography (DDR). In this presentation, I will mainly report the comparison with pulmonary perfusion scintigraphy.

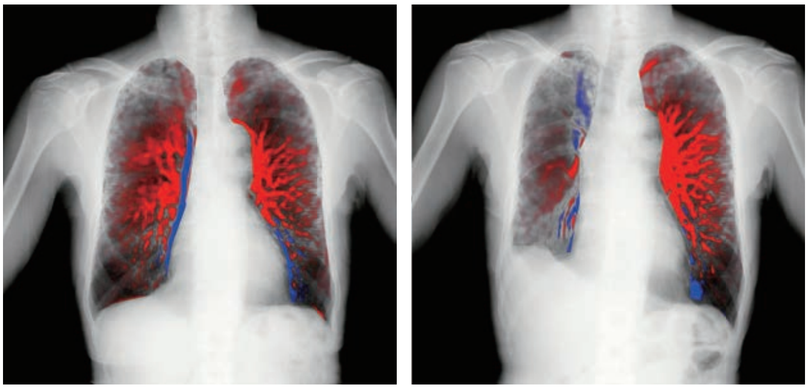
Evaluation of pulmonary circulation : Comparison with pulmonary perfusion scintigraphy

We compared the relative perfusion contribution by DDR and that by the pulmonary perfusion scintigraphy. The subjects were 26 patients (7 before surgery and 19 after surgery) who underwent Dynamic Digital Radiography and pulmonary perfusion scintigraphy during the same period, and 23 patients of them had lung cancer. The lung field was divided into six zones, and the relative perfusion contribution of each zone was measured by the improved PH-MODE (Cross-correlation calculation) of the DDR and pulmonary perfusion scintigraphy. Then, the relative perfusion contribution of each zone by pulmonary perfusion scintigraphy was plotted on the X-axis, and that of DDR was plotted on the Y-axis, and the correlation between those was analyzed. If the correlation coefficient was <0.2, it is regarded as no correlation, if that was 0.2-0.4, regarded as weak correlation, if that was >0.4, regarded as correlation, and P value <0.05 was regarded as significant difference.

There was a significant correlation between the relative perfusion contribution by DDR and that of pulmonary scintigraphy in the right upper lung field, right middle lung field, and right lower lung field. On the other hand, as for the left lung, the left upper lung field and left middle lung field showed correlation, but the left lower lung field did not show significant correlation. This seems to be due to the cardiac shadows. From these results, it can be said that the DDR would be an alternative examination for lung perfusion evaluation.

Based on this, we will present a case. This patient was 78-year-old man who underwent resection of the right upper lobe lung cancer. Three months after the operation, his dyspnea worsened, and he was

Pre- and Postoperative DCR (Cross-correlation calculation processing)



a: Preoperative b: Postoperative

Fig. 1 Improved PH-MODE for resection of right upper lobe lung cancer

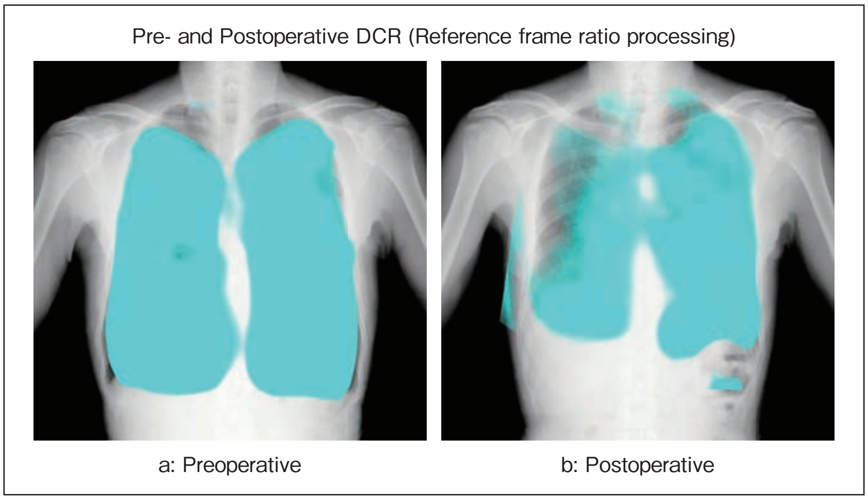


Fig. 2 PL-MODE of the same patient as Fig. 1

re-examined. Lung ventilation and perfusion scintigraphy showed that both ventilation and perfusion of the right lung were significantly lower than those of left lung. DDR was also captured for this patient and analysis was performed. In comparing the preoperative and postoperative images of the DDR, postoperatively the movement of the vascular shadow in the right lung field reduced(PH-MODE) and the movement of the diaphragm was abnormal. Abnormalities in the mediastinum movement were also observed by PL-MODE (Reference frame ratio processing) **(Figs. 1 and 2).** As described above, the DDR can capture dynamic function information that cannot be obtained by other modalities.

Detection of pleural adhesion

We have been studying the application of the DDR to thoracic surgery. In order to examine the indications for preoperative pleural adhesion diagnosis, preoperative DDR of 151 patients who underwent thoracic surgery were captured. Abnormal factors suggesting adhesion were extracted from DDR , and the presence or absence of adhesion and its degree were also evaluated based on the video captured during the surgery as the reference, in order to check if pleural adhesion could be detect by DDR image before surgery. The abnormal factors, which is DDR image feature of pleural adhesion based on our expertise, included the following three signs such as “Gradation sign (G-sign)” with abnormal pulmonary vascular/bronchial movement, “Fixed sign (F-sign)” with fixed pulmonary vascular/bronchi with no movement, and “Tension sign (T-sign)”, which moves as if the funicular shadow were pulled.

The sum of those three findings (0/1/2/3) was used as the pleural adhesion prediction score (PAPS), and the grade of the adhesion was classified into following 5 categories; Grade 0: no adhesion, Grade 1: localized adhesion, Grade 2: adhesion in thorax 1/3 or less, Grade 3: adhesion in thorax 1/3 to 2/3, and Grade 4: total adhesion. In addition, we examined whether adhesion of moderate (Grade 2) or higher could be detected using PAPS of 2 or more as a cutoff line.

As a result, pleural adhesion was hardly observed in the low-risk groups with PAPS of 0 or 1, and pleural adhesion was more observed in the high-risk groups with PAPS of 2 or 3 with a sensitivity of 95% and a specificity of 96%. From this, it can be said that the use of PAPS obtained by the DDR would be able to predict moderate or more pleural adhesions.

Conclusion

The DDR is inexpensive, easy to operate, has high versatility, and lower dose compared to pulmonary blood flow scintigraphy, and useful for predicting postoperative pulmonary function and for searching the cause of pulmonary function decline after lung resection. Furthermore, it is possible to detect dynamic abnormal findings during thorax movement with the DDR, which was difficult to evaluate in the past. Based on these findings, DDR may be a potential alternative to pulmonary perfusion scintigraphy, and it can predict moderate or more pleural adhesions, and can also be used to evaluate adjacent organ invasion in some cases.

Prediction of postoperative pulmonary function using Dynamic Digital Radiography

Jun Hanaoka, MD, PhD Division of General Thoracic Surgery, Department of Surgery, Shiga University of Medical Science

The number of lung cancer patients with poor pulmonary function has been increasing, and it is important to evaluate strictly indications and risk factors for radical surgery for lung cancer. In this presentation, we report the validation of prediction of postoperative pulmonary function using the relative perfusion contribution by Dynamic Digital Radiography (DDR).

Validation of prediction of postoperative pulmonary function using DDR

Perioperative risks of lung resection are related to predicted postoperative pulmonary function such as FEV1 and FEV1 expressed as % predicted. Postoperative pulmonary function has been evaluated based on preoperative spirometry and the number of segments to be resected. However, it is necessary to improve its accuracy in cases near the threshold value. There are several published paper demonstrated that the accuracy can be improved by taking the relative perfusion contribution by perfusion scintigraphy into consideration, but there are problems such as labor, cost, exposure, and lack of urgency. Therefore, we conducted the study on the patients who underwent radical surgery for primary lung cancer to validate a prediction method of postoperative pulmonary function which is taking the perfusion information by DDR account.

1. Subjects and methods

The 34 patients who underwent radical surgery for primary lung cancer in our department were included. Preoperative DDR was captured for all patients and, the left and right perfusion contribution ratios were calculated from pixel values change corresponding to the pulsation of pulmonary artery during the cardiac cycle. Spirometry was measured before surgery and at 1, 3, and 6 months after surgery to evaluate the FEV1. The correlation between FEV1 measured value and the predict postoperative FEV1 three different methods; 1)the conventional method based on the number of segments to be resected, 2)the method taking perfusion contribution ratio calculated from perfusion scintigraphy and 3)the method taking perfusion contribution ratio calculated from DDR were evaluated with the Pearson's correlation coefficient (R).

2. Result (*Fig. 1*)

There was a strong correlation between the perfusion contribution ratio of perfusion scintigraph and

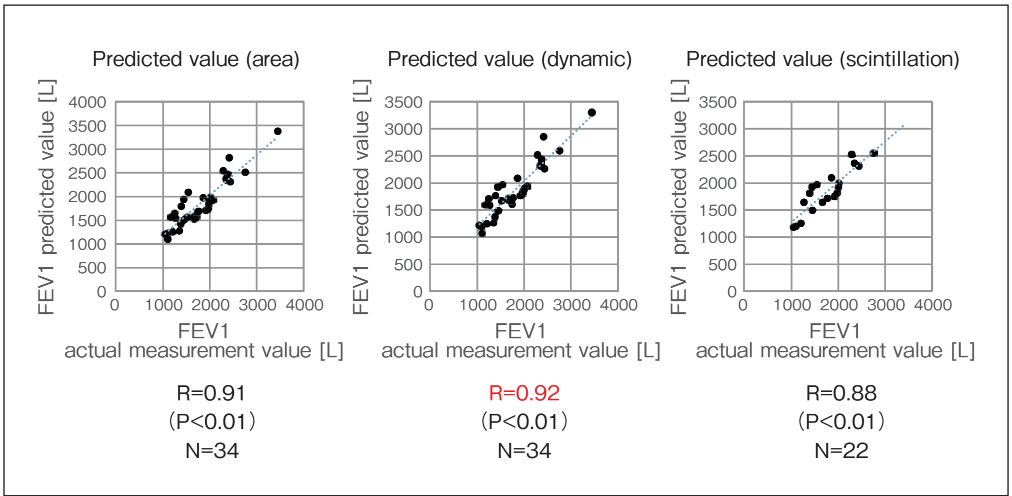


Fig. 1 Measured and predicted FEV (one month after surgery).

that of DDR (R=0.90, p<0.01, n=22). The correlation between the FEV1 measured value one month after surgery and predicted postoperative FEV1 by three different method were strong as 1) R=0.91, 2) R=0.92 and 3) R=0.88 (all p<0.01). Similar tendency was observed at three months after surgery; 1) R=0.94, 2) R=0.94 and 3) R=0.94 (all p<0.01), and at six months after surgery; 1) R=0.94, 2) R=0.94 and 3) R=0.91 (all p<0.01)

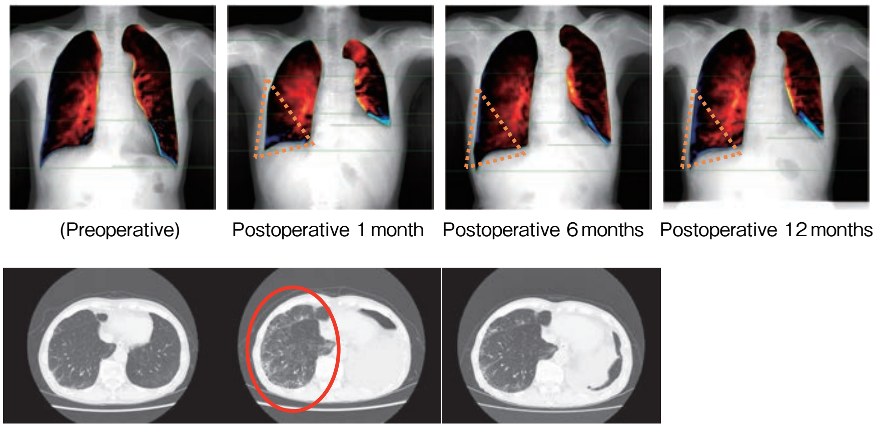


Fig. 2 Evaluation of postoperative pneumonia

3. Discussion

The postoperative prediction FEV1 using the perfusion contribution ratio obtained from DDR showed a high correlation with the measured FEV1 values. However, there was no significant difference in the prediction accuracy between the three methods, which was presumed to be due to the small variation in perfusion contribution among the patients. Compared to scintigraphy, DDR have the advantage of being able to obtain functional information at the same time as static chest radiography, and have the advantage of being a simple, short-time and lower radiation dose exam. As future tasks, it is considered necessary to increase the number of cases, examine the prediction accuracy of the surgical side and by the resected lung, evaluate cases with uneven perfusion contribution, and evaluate with other pulmonary function indices.

Cases for which blood flow evaluation is expected to be useful

1. Evaluation of postoperative pneumonia (Fig. 2)

The patient had chronic obstructive pulmonary disease (COPD), and underwent resection for left upper lobe lung cancer. Preoperative CT showed ground-glass opacities in the right lung. One month after the operation, the patient complained of malaise and breathlessness. A static chest radiography was taken, but no findings were found. CT scan revealed a magnified glassy shadow, suggesting exacerbation of pneumonia. In DDR taken at the same time, a decrease in blood flow was suggested in accordance with the shadow area of the CT. Improvement was seen at six months after the operation, and almost one year later the patient recovered. Postoperative pneumonia that were not apparent on static chest radiography could be evaluated by DDR.

2. Confirmation of the effect of hyperinflation of the remaining lung on the operation side

The patient had COPD and underwent resection of the left upper lobe lung cancer. Preoperatively, the blood flow on the left side slightly reduced, and postoperatively, the blood flow in the lower left lobe continued to significantly reduce. When the volume of each of whole lung lobe was measured from the CT data at the workstation, preoperatively the remaining lower lobe on the operation side was 896 mL whereas at 6 months postoperatively it was 1,255 mL, which is hyperinflation of about 1.5 times. It was considered that the blood volume relatively decreased due to hyperinflation.

Conclusion

According to this study, the perfusion contribution ratio calculated by DDR was similar to that of perfusion scintigraphy. In addition, it was suggested that more accurate predictions could be made by adding the perfusion contribution ratio of DDR to the conventional postoperative pulmonary function prediction method. DDR can be more easily taken to evaluate blood flow, and are considered to be useful methods that can be expected in the future.

Evaluation of pulmonary function by Dynamic Digital Radiography: basic study in cynomolgus monkeys

Hidemitsu Miyatake, MD Department of Critical and Intensive Care Medicine, Shiga University of Medical Science

We report the evaluation of pulmonary blood flow and detection of pulmonary embolism using cynomolgus monkeys by Dynamic Digital Radiography (DDR).

Purpose of this study

In recent years, pulmonary embolism following a large-scale natural disaster has become a topic in cardiovascular care. Contrast-enhanced CT is the gold standard for diagnosing pulmonary embolism, but there are risks such as radiation, allergy, and renal dysfunction, and it can be performed only in facilities equipped with CT and other equipment. On the other hand, DDR can evaluate the motion of the lungs, blood flow, and the motion of the heart with a minimally invasive motion image. Therefore, we examined whether it is possible to evaluate pulmonary blood flow in the supine and standing positions and detect pulmonary embolism(PE) using the cynomolgus monkey by DDR.

Methods&Results

1. Experiments with cynomolgus monkeys

In this study, five cynomolgus monkeys were intubated and fixed on a table, and a pulmonary blood flow obstruction model was created by inserting a Swan-Ganz catheter. Then, the pixel values of DDR images in both lung field of the normal model and the PE model were compared.

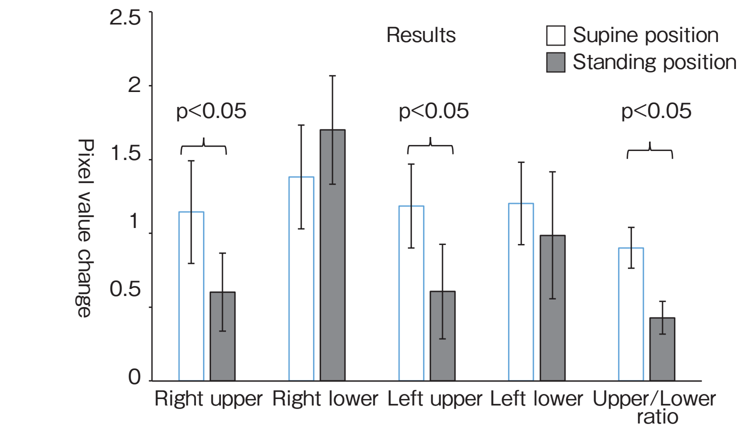
In this study, we developed a bed that could be rotated 90° vertically and captured DDR image in supine and standing positions. DDR image for eight seconds was taken under stop breathing. As an analysis method, Region of Interest (ROI) were set at the top, bottom, left, and right of the lung field of the taken images, and the average and maximum change of the pixel values in each ROI during one cardiac cycle was measured. In addition, the difference in pixel values between the left and right lungs of the normal model and those of the PE model was analyzed using SPSS, and a color-coded image of the pixel value change of DDR was also created.

A periodicity was observed in the waveform of the pixel values change in the normal model. The waveform that change in similar cycle as ECG was extracted with removing low frequency component, which is corresponding to respiratory cycle. There was no significant difference between the pixel value change at upper lung field and that at lower lung field in supine position. On the other hand, in the standing position, there was a significant difference in the range of the pixel value change in the upper lung field and that in the width of change in the lower lung field. Statistical analysis revealed that in the normal model, the pixel value change rate was lower in the standing position than in the supine position, and in both the left and right upper lung fields, the pixel value in standing positions was significantly lower. This result suggested that in the standing position, blood flow amount in the lower lung field would be less than that in the upper lung (**Fig. 1**).

On the other hand, in PE model, the range of the pixel value change in left lung, where the pulmonary artery was occluded, decreased, and that in right lung where occlusion wasn't there, increased significantly. In addition, on the color-coded image, the lower left lung field was less red-colored and much black-colored than the lower right lung field. Statistical analysis showed that there was no difference between the range of pixel value change in left and that in right in normal cases, but in PE model, the range of the pixel value change on the occluded side was significantly less than that on the un-occluded side (**Fig. 2**).

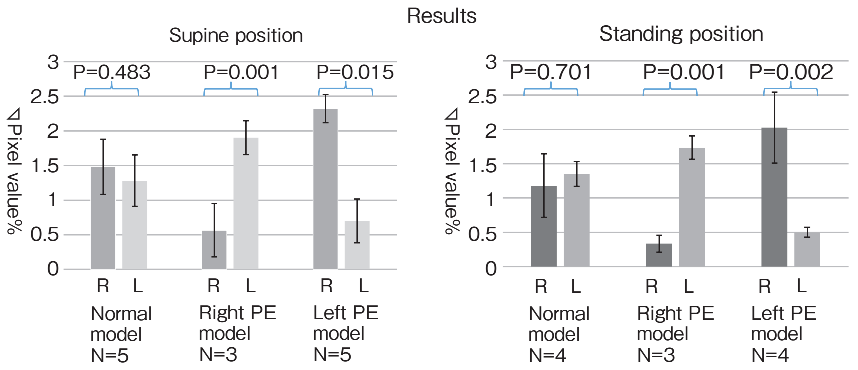
From those results, it can be said that (1) the pixel value change in lung field has similar cycle as ECG, which is Pulsation, after removing low frequency component. (2) the amount of the pixel value change in the upper lung field is less than that in the lower lung field at the standing position when compared with in the supine position, and (3) the amount of the pixel value change at occlusion site is less than that in the non-occlusion site.

The amount of pixel value change would be corresponding to the blood flow amount, and it would be thought that either the change in pulmonary artery pressure or diameter is cause of the pixel value change in this case.



In the upper lung field, the pixel values on both the left and right sides decreased significantly in the standing position.

Fig. 1 Pixel value change difference between supine and standing positions



Compared with the normal model, in the pulmonary embolism model, the pixel value change decreased on the embolism side and increased on the non-embolism side.

Fig. 2 Comparison of the pixel value change rate between normal model and PE model

2. Experiment with vessel phantom

As an additional experiment, DDR image of two types of vessel phantom was captured. A pressure sensor was connected to an artificial blood vessel and a pressure-resistant tube (both were filled with physiological saline) and pressure was manually applied to both. The pixel change of DDR image was observed. As a result, in the artificial blood vessel, the correlation between the pixel value and the pressure was observed, but not for the pressure-resistant tube. This suggests that the pixel values change of DDR image would reflects dilation of artery rather than pressure.

Conclusion

From this study, it was suggested that the amount of change in the pixel value of the lung is correlated with the pulmonary artery blood flow. Compared with conventional contrast-enhanced CT and pulmonary perfusion scintigraphy, DDR may be able to diagnose PE earlier, less invasively, at lower cost, and at various places outside the hospital. It is thought to be useful diagnostic tool for disaster medical care.

There were several limitations in this study. The cynomolgus monkeys used in this experiment generally do have arteriosclerosis. On the other hand, human do have that and also there would be a variety of factors affecting the pixel value change, so future investigation is required.

DDR is a simpler and less invasive method for evaluating pulmonary blood flow compared to existing imaging modality, and is useful for detecting diseases that cause decreased blood supply such as PE.

Based on this study, we are currently making an application to the Ministry of Health, Labour and Welfare for a prospective study DDR for heart failure and PE in humans.

Study on new pulmonary function evaluation method using Dynamic Digital Radiography

Noriyuki Ohkura, MD Department of Respiratory Medicine, Kanazawa University

We have been studying the clinical application of Dynamic Digital Radiography (DDR). In this presentation, we report the study results on the change rate of lung area due to respiratory variability.

Introduction

Chest DDR can evaluate the pulmonary function in a minimally invasive and simple manner, and visualize and observe the pulmonary function. We examined the change rate of lung area due to respiratory variability using chest DDR in patients with obstructive ventilatory defect and interstitial lung disease.

Study in obstructive ventilatory defect

In this study, of the 233 patients who underwent chest DDR, 118 patients with preoperative lung cancer with FEV1% < 70%, chronic obstructive pulmonary disease (COPD), bronchial asthma, and asthma and COPD overlapping syndrome (ACO) were included. Of these, 87 were males, the average age was 71.4 years, and they were a mild COPD population. FEV1% = 59% on average, % FEV1 = 95.9% on average, which was considered as mild airflow limitation, and % maximum expiratory medium flow (% MMF) = 28% on average, Residual Capacity (RV) was elevated and Lung Diffusion Capacity (DL_{CO}) was decreased. As for the relationship between the change rate of lung area and Body plethysmography results(lung volumes) and Spirometry results, the results showed that the lung volumes such as RV had a higher correlation value than Spirometry results such as FEV1 **(Table 1)**. The highest is RV, which is considered as hyperinflation. Furthermore, when the patients were stratified based on FEV1 (FEV1 ≧ 80%: mild case, 80%>FEV1 ≧ 50% : moderate case, FEV1< 50%: severe case), mild cases are not much different from normal cases, but the change rate of lung area decreased as the disease progressed from moderate to severe, indicating that the change rate of lung area decreased as the airflow restriction progressed.

In addition, in comparison of each parameter with that of the MostGraph, which can visualize pulmonary function under ventilation at rest, the values of airway resistance and respiratory reactance were all significantly correlated, and it was considered to be related to airflow restriction and imbalanced ventilation.

The patient was 53-year-old man, who had obstructive ventilatory defect during preoperative pulmonary function test **(Fig. 1)**.

Table 1 Relationship between the change rate of lung are and lung volumes in obstructive ventilatory defect .

Relationship of lung area change rate (Rs) with lung volume fraction and forced exhalation curve in patients with obstructive ventilatory defect (n=118)

	Rs	
	r	p
VC (% pred.)	-0.29	<0.01
FVC (% pred.)	-0.28	<0.01
FEV_1 (% pred.)	-0.33	<0.01
FEV_1/FVC	-0.19	0.04
MMF (% pred.)	-0.26	<0.01
FRC (% pred.)	-0.14	0.12
RV (% pred.)	0.31	<0.01
TLC (% pred.)	-0.01	0.93
RV/TLC ratio	0.48	<0.01
DL_{CO} (% pred.)	-0.12	0.18

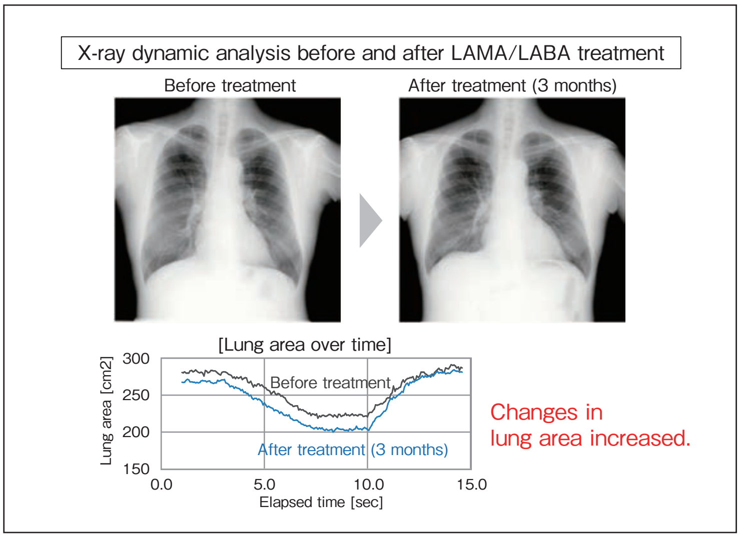


Fig. 1 Case: 53-year-old male patient with COPD

Table 2 Relationship between the change rate of lung are and lung volumes in interstitial lung disease

Relationship of lung area change rate (Rs) with lung volume fraction, and forced exhalation curve in patients with interstitial lung disease (n = 40)

	Rs	
	r	p
VC (% pred.)	-0.43	<0.01
FVC (% pred.)	-0.43	<0.01
FEV_1 (% pred.)	-0.32	0.04
FEV_1/FVC	0.09	0.56
MMF (% pred.)	-0.06	0.70
FRC (% pred.)	-0.16	0.32
RV (% pred.)	0.01	0.94
TLC (% pred.)	-0.19	0.23
RV/TLC ratio	-0.39	0.01
DL_{CO} (% pred.)	-0.27	0.11

The patient had no complications or a history of bronchial asthma or rhinitis, but was the current smoker with a CAT score of 15. %FEV1 was 49.7%, RV increased, DL_{CO} decreased, and COPD was suspected from symptoms and function. When anticholinergic inhalant (LAMA) and β2-agonists (LABA) were administered, the change rate of lung area increased after certain period.

Study in interstitial lung disease

In this study, of 40 patients with interstitial lung disease were studied among 233 patients who underwent DDR. The patients were composed of mainly idiopathic pulmonary fibrosis (IPF), scleroderma, and interstitial lung disease with progressive fibrosis with decreased vital capacity (VC), restricted dysfunction, DL_{CO} as low as 38.3% on average. As for the relationship between the change rate of the lung area, lung volumes, and Spirometry, in the case of obstructive ventilatory defect, they were significantly correlated, and correlation with the residual volume rate (RV/TLC) was also found **(Table 2).** When the patients were stratified based on %VC (mild : 80% ≧ %VC, moderate: 80%> %VC ≧ 65%, severe : %VC ≦ 65%), the change rate of lung area becomes lower in moderate and severe cases as in the case of obstructive ventilatory defect, and the change rate of lung area also decreased with a decrease in %VC. The relationship between the change rate of lung area and the 6-minute walking distance was examined in 20 patients with interstitial lung disease. The results showed that the lower the change rate, the shorter the walking distance, which indicated a correlation with physical activity. This indicated that it would be possible to evaluate exercise tolerability by DDR.

Conclusion

The change rate of lung area in obstructive ventilatory defect reflects airflow restriction and a hyperinflation. The lower change rate of lung area in interstitial lung disease reflects lower %VC and less exercise tolerance. Based on those results, it was confirmed that DDR would be an imaging modality that was clinically useful as a new method for evaluating pulmonary function. In the future, it is necessary to study more detailed analysis such as the type and stage classification on various disease, and the application of artificial intelligence (AI) for that purpose would be expected.

Study on clinical usefulness of tracheal diameter evaluation using Dynamic Digital Radiography

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Since Dynamic Digital Radiography(DDR) enables direct observation of tracheal movement, it may be a convenient tool for screening patients with ventilatory disorders such as tracheomalacia and Excessive Dynamic Airway Collapse where the trachea moves during inspiration and expiration. In this presentation, we will introduce a study on tracheal diameter evaluation using DDR.

Method

Of the patients scheduled to undergo thoracic surgery at our hospital, 52 patients with written consent participated in the study. DDR image was captured in the supine position. The patient was forced to breathe according to the voice guidance, and DDR imaging was taken for 15 seconds from maximum inspiration to expiration and inspiration at frame of 15 fps.

Results

Result 1: Difference in the degree of tracheal narrowing depending on the type of ventilation disorder

Of 52 patients, 7 patients who underwent Spirometry at another hospital and 1 patient with mixed ventilation disorder were excluded, and 28 normal subjects, 12 patients with obstructive ventilatory defect and 4 patients with restricted ventilation disorder were included. The diameter of the trachea at the start of expiration (the most dilated) and the trachea at the end of expiration (the narrowest) were measured. The measurement location was between the caudal side of the sternoclavicular joint and one vertebral head side of the tracheal bifurcation.

As a result, the tracheal diameter was significantly narrowed in the obstructive ventilatory disorder group compared to the normal group and the restrictive ventilation disorder group **(Fig. 1)**. In the obstructive ventilatory disorder group, the trachea was considered likely to be narrowed during expiration.

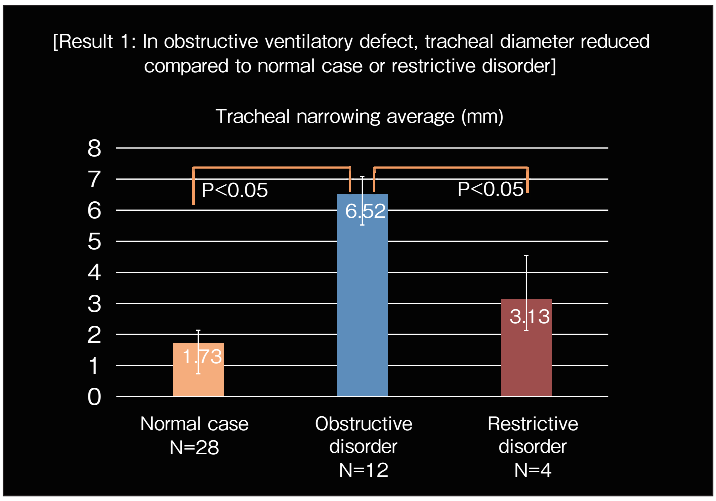

Fig. 1 Result 1: Degree of tracheal narrowing by type of ventilation disorder

Result 2: Inter-observer differences

Three observers, who did not know the results of Spirometry, measured manually the diameter of the trachea at the start of expiration (most dilated) and the trachea at the end of expiration (most narrowed) in 28 normal subjects and 12 patients with obstructive ventilatory disorder.

As a result, there was no large difference in the results between the measurers, and the trachea tended to be narrowed in the obstructive ventilatory disorder group at the time of expiration as in result 1. Therefore, it is considered that obstructive ventilatory defect may be detectable by DDR.

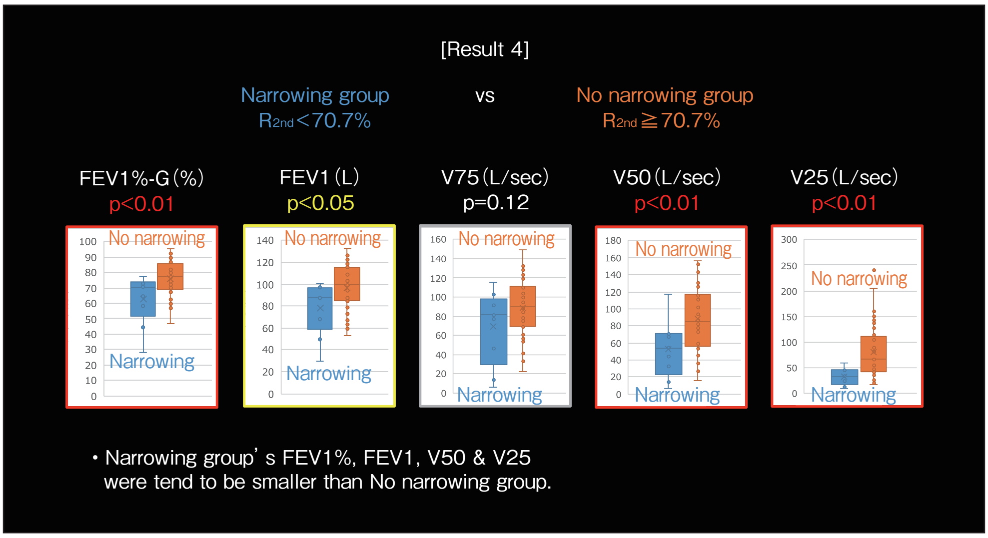

Fig. 2 Result 4: Relationship between tracheal narrowing and pulmonary function test

Result 3: Reduction of measurement errors

In order to reduce the impact of tiny fluctuation during breathing on the measurement accuracy, the average value of trachea diameter during certain period was used for the evaluation. The measurement location was the midpoint between Th2 and the bronchial bifurcation. Four patients with obstructive ventilatory disorder and four normal subjects were randomly selected, and the tracheal diameter was manually measured for 15 seconds (225 frames per person). From the obtained data, the change rate of the tracheal diameter was calculated from the average diameter at the start of expiration and at the end of expiration. The diameter for 1 sec, which is a total 15 diameter values, were used for averaging. As a result, it was confirmed that the change rate in tracheal diameter tended to be small due to obstructive ventilatory disorder.

The question like, the same result can be obtained by static chest radiography at the maximum inspiration and expiration, may be arisen. However, the movement of the diaphragm does not always match the movement of the trachea, and it has been reported that a hard breathing leads to more severe tracheal narrowing. Therefore, it was suggested that DDR would be better tool for evaluating tracheal narrowing .

Result 4: Relationship between changes in tracheal diameter and pulmonary function test

We verified whether there was a relationship between the change rate of tracheal diameter and pulmonary function in 28 normal subjects and 12 patients with obstructive ventilatory disorder. The change rate of tracheal diameter at the time of starting and ending of the was measured. In this study, subjects were divided into a group; tracheal diameter narrowing (diameter change ≦70.7%) and a group with non-narrowing.

As a result, among the pulmonary function test results, the values of 1 second rate (FEV1%), V50, and V25 were significantly correlated to the change in tracheal diameter **(Fig. 2).** Those results suggested that patients with abnormal pulmonary function could be detected by tracheal diameter narrowing evaluation.

Conclusion

The number of patients in this study was very small and there is also several limitations such as measurement accuracy and measurement labor because the all measurement should be performed manually. The relationship between the degree of tracheal diameter narrowing and the severity of obstructive ventilatory defect will also need to be examined.

DDR can dynamically observe the narrowing of the tracheal diameter that occurs during expiration, and it would be possible to identify and evaluate the severity of patients with obstructive ventilatory defect by observing and measuring tracheal narrowing. The development of software that can measure and evaluate the tracheal diameter more objectively and efficiently is our current task.

Dynamic Digital Radiography : Method on chest application

Ryotaro Yuji Radiological Technology Department, Clinical Technology Division, Tokai University Hachioji Hospital

In January 2018, our hospital introduced the first Dynamic Digital Radiography (DDR) system in the world and started clinical research. In this presentation, we will report the outline of the system and the actual flow and points of DDR for chest application.

Evolution from static x-ray image to dynamic x-ray image

In the DDR, it becomes possible to create an motion x-ray image having a time resolution in addition to a spatial resolution by adding a time axis to a conventional x-ray.

The work of medical X-ray technicians is also changing from “taking pictures” to “taking videos”. Compared with conventional x-ray, DDR requires more appropriate positioning and understanding/cooperation of patients for examination in order to capture the patient's disease condition. In addition, the examination may be performed a plurality of times because it can be a functional inspection, and the reproducibility is also important.

Overview of DDR and examination

The DDR system is composed of Konica Minolta's x-ray dynamic image analysis workstation "KINOSIS", portable digital x-ray imaging device "AeroDRfine", and Shimadzu Corporation's general imaging device "RADspeedPro". As a supplementary function of a conventional radiography system, a dynamic x-ray image (a sequential radiography) can be captured with pulsed x-rays exposure at 15 frames per second, and the obtained images are displayed as a movie. This movie has a spatial resolution of 400 μm and a gray scale image density resolution is 16 bits.

The normal procedure of conventional radiography is to check the patient condition and explain how the exam is going to be, set the exposure conditions, conduct positioning and exposure, check whether the image has been properly captured and processed, and deliver to physicians. In addition, DDR requires a more detailed explanation before the examination, attention to patient positioning, and practice of breathing to obtain maximum inspiration and expiration **(Fig. 1).** Prior explanation is particularly important for obtaining patient cooperation. In our hospital, a leaflet for the examination guide were prepared and the all patient is asked to read carefully before the examination.

In positioning, in order to reduce unnecessary tension of muscle used for breathing, the handle shall be grasped in a comfortable position, and the height of the forearm and

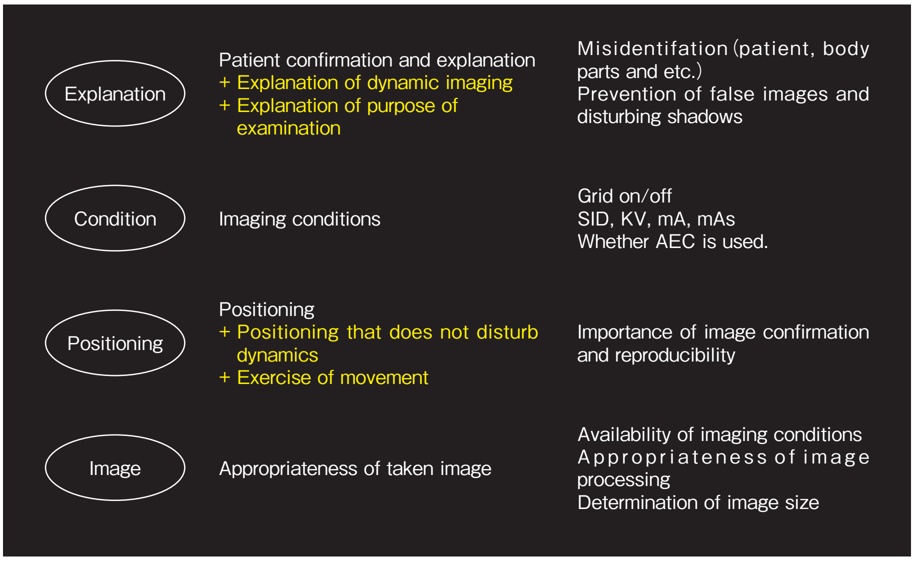

Fig. 1 Procedure Flow of DDR

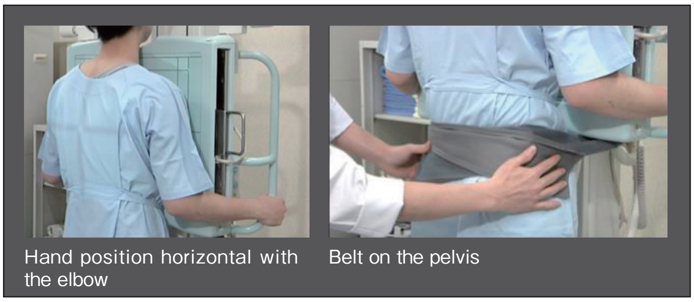

Fig. 2 Key Points of Positioning

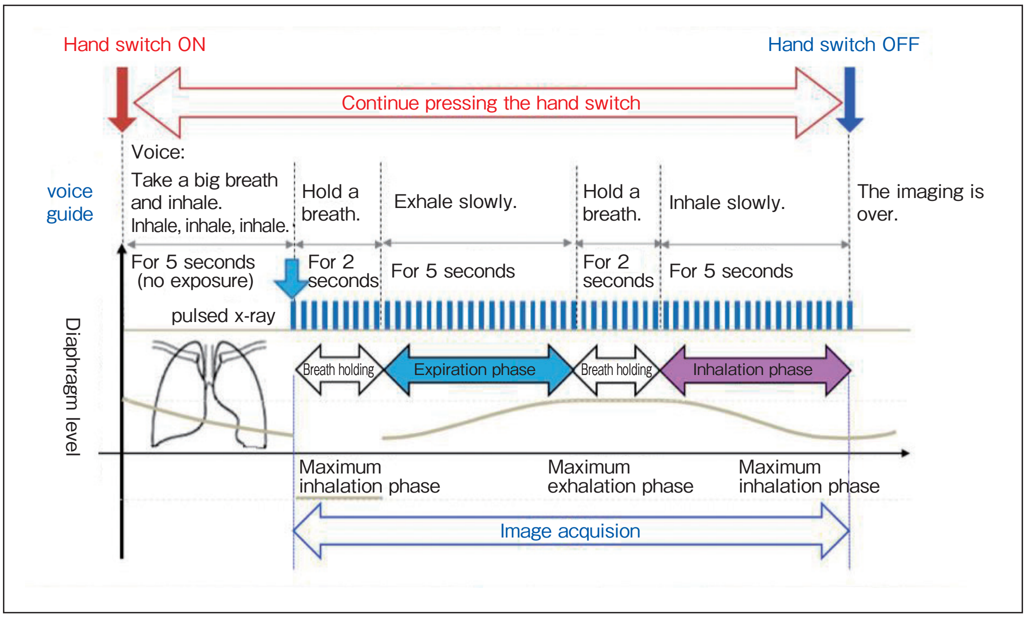

Fig. 3 An example of breathing pattern (Deep breathing) with voice guide

wrist shall be horizontal so that the upper arm muscles won't have unnecessary tension. The pelvis shall be fixed with a belt to prevent body movement (**Fig. 2**).

To improve the reproducibility of the examination, automated voice guide is used for breathing instructions (**Fig. 3**). In addition, the voice guide can be operated for breathing practice in the radiographing room, so that the medical X-ray technicians can confirm how the voice is heard and how the body of the patient moves near the patient. By unifying the timing of the start of radiography among the operator in the radiology department, there is almost no difference among medical X-ray technicians at present.

The exposure dose (entrance surface dose) is calculated as 1 pulse dose × 15 fps × imaging time (seconds). In our hospital, the average scan time was 16.6 seconds, and the average exposure dose was 1.82 mGy, which is lower than the International Atomic Energy Agency (IAEA) guidance level of 1.9 mGy for the front and side of the chest. In addition, it is possible to perform examinations at a much lower exposure dose than our low-dose lung CT screening.

Regarding the procedure of DDR, a manual was prepared by our hospital and Konica Minolta to ensure consistency of the examination. As a result, the average examination time from the patient's calling to leaving the room at our hospital is 4.9 minutes.

Conclusion

With a leaflets for the patient and procedure manuals for medical X-ray technicians, high reproducible examinations are possible, and our hospital has realized a system that can immediately respond to exam order of DDR. In addition, it is expected that the DDR would be useful tool for the orthopedic application as well as the chest application in the future.

Medical X-ray technicians are also required to have a new role, including understanding of respiratory physiology, and we believe that DDR is one of the challenging modalities for medical X-ray technicians.

Focusing on patients with COPD, and Ventilation defect

Fumio Sakamaki, MD Department of Respiratory Medicine, Tokai University Hachioji Hospital/Respiratory Division, Department of Internal Medicine, Tokai University School of Medicine

In our hospital, about 100 cases of Dynamic Digital Radiography (DDR) have been captured by October 2019 using Konica Minolta's DDR system. In this presentation, we report the results of thoracic cage movement in patients with chronic obstructive pulmonary disease (COPD), and report the usefulness and potential of this system in COPD and alveolar hypoventilation syndrome.

Study on thoracic cage movement in COPD patients

1. Background and purpose

In COPD, it is known that the diaphragm becomes flat due to hyperinflation of the lungs, and paradoxical movements of the diaphragm and deterioration of movement have been reported. On the other hand, in severe COPD, abnormal movement of the ribs in the lower rib cage (Hoover's sign) has been known for a long time, but there are few quantitative studies on this movement. We analyzed the coordination of the posterior ribs and the movement of the diaphragm from DDR in 31 patients with suspected COPD and compared mainly with the pulmonary function test[1].

2. Method

At the time of expiration and inspiration, a fixed point was set immediately below the pleura of the posterior rib, and the change in the moving angle of the fixed point was automatically tracked by special software to calculate the direction of movement. The angle of the movement of the posterior rib between the upper-middle lung field, the middle-lower lung field, and the upper-lower lung field was calculated, and the similarity of the movement between the ribs was compared.

3. Results

As for the similarity of the movements of the posterior ribs in the mild group and the severe group, the lower rib moved in a different direction from the upper and middle ribs in the mild group, whereas it moved in the same direction in the severe group. On the other hand, there was no difference in diaphragm movement due to airflow limitation. In addition, a correlation was found between the airflow limitation (% FEV1) and similarity. We conclude that there is a possibility that the severity of COPD can be evaluated visually and objectively using DDR.

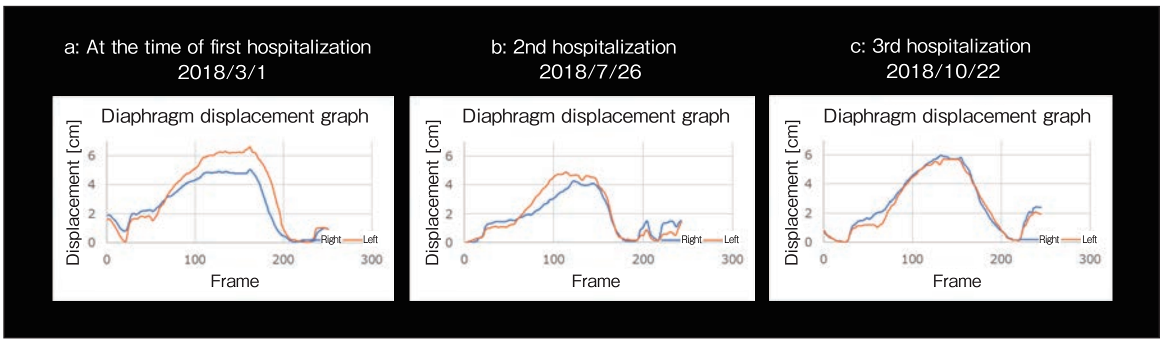

Fig. 1 Case 1: Diaphragm Excursion

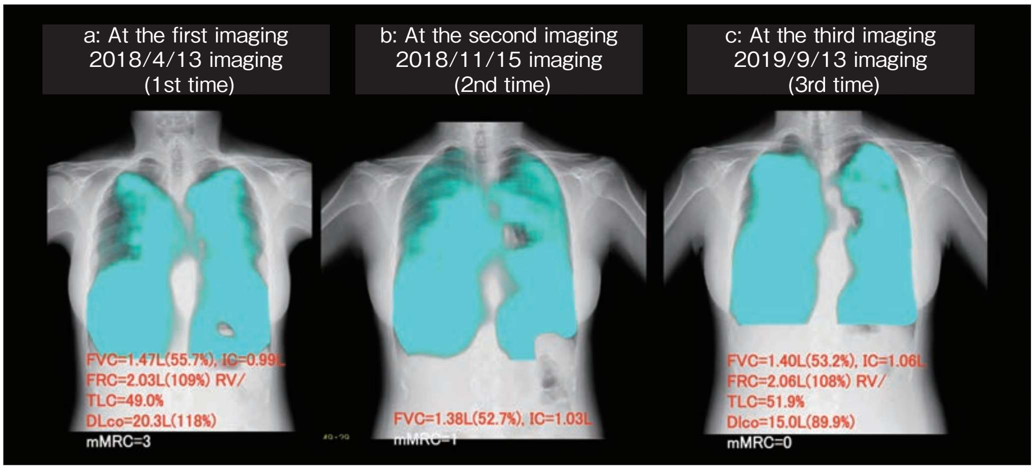

Fig. 2 Case 3: PL-MODE on alveolar hypoventilation syndrome patient

Case presentation

Case 1: Severe case of COPD (follow-up case)

This patient was hospitalized 3 times in 2018 due to worsening symptoms. Dyspnea and airflow limitation were severe, and the severity classification of COPD (ABCD classification) was as severe as D. Treatment was conducted focusing on LABA/LAMA combination drugs and inhaled steroids (ICS), and the stable trend of patient condition began in 2019.

On DDR, the lung was slightly hyperinflated and the heart looked like “drop heart”, but FEV1 recovered slightly over time. There is no change over time in the movement of the posterior ribs, but the displacement graph of the diaphragm (**Fig. 1**) shows a smooth up and down movement without any imbalance between the left and right and COPD-specific shaking at the third hospitalization. It is expected that the improving effect of pulmonary function could be confirmed from the displacement of the diaphragm.

Case 2: Patient with moderate to severe COPD

This patient had %FEV1 ≃ 53%, which means this patient was moderate to severe COPD, and was hospitalized once due to exacerbation and had shortness of breath. FE-MODE (Frequency enhancement processing) of DDR image can confirm trachea narrowing during expiration, which is frequently observed in severe cases.

Case 3: Alveolar hypoventilation syndrome (follow-up case)

The patient was diagnosed with idiopathic pulmonary arterial hypertension at another hospital, but it was considered to be type II respiratory failure according to the results of pulmonary function test. The decreased mobility of the diaphragm detected on DDR images cannot be ruled out as a cause of hypercapnia, and noninvasive positive pressure ventilation (NPPV) was conducted during sleep, which improved subjective symptoms.

There was no change over time in forced vital capacity (FVC), but the maximum inspiratory volume (IC) increased from 0.99 L to 1.06 L. Furthermore, the improvement of ventilation was confirmed in the PL-MODE (Reference frame ratio calculation processing) image (**Fig. 2**), and the shortness of breath index (mMRC) was also improved. Pulmonary circulation improvement was observed in PH-MODE (Cross-correlation calculation processing). We believe that DDR could be an index of ventilation evaluation.

Conclusion

In COPD and alveolar hypoventilation syndrome, quantitative evaluation of posterior rib and diaphragm movements on DDR images can be an index for severity evaluation and time-course observation. We also believe that it would be possible to visually evaluate the rib cage movement, abnormality on the central airway, ventilation imbalance and pulmonary circulation defect.

●References

1) Genki Takahashi et al., *Annals of the Japanese Respiratory Society*, 8 (Suppl.): 262, 2019.

Study on application to chronic respiratory disease

Takefumi Nikaido, MD, PhD Department of Pulmonary Medicine, Fukushima Medical University

We introduced Dynamic Digital Radiography (DDR) to evaluate pulmonary circulation for chronic pulmonary thromboembolism. Furthermore, recently, we tried to apply DDR to chronic respiratory diseases. In this presentation, we present a case of interstitial pneumonia and emphysema with giant bullae as an initial study.

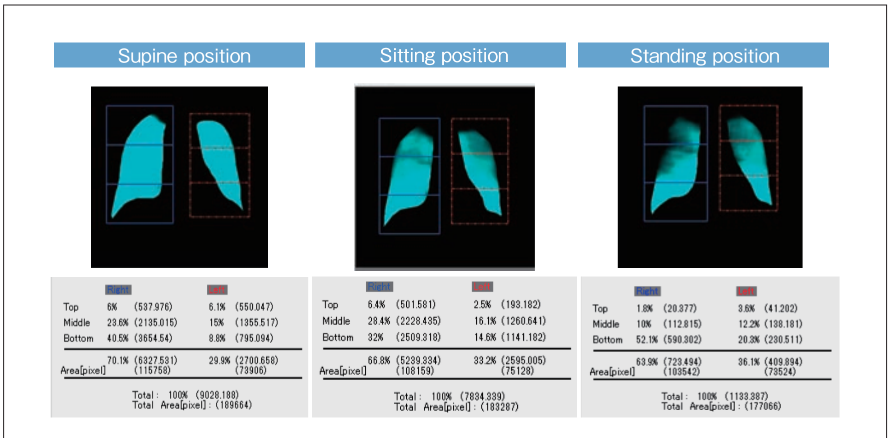

Fig. 1 Case 1: Interstitial Pneumonia. Ventilation evaluation image

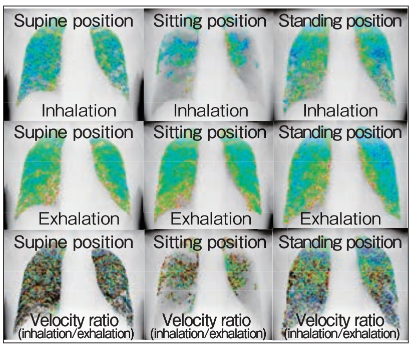

Fig. 2 Case 1: Interstitial Pneumonia. Airflow velocity analysis image during tidal breathing

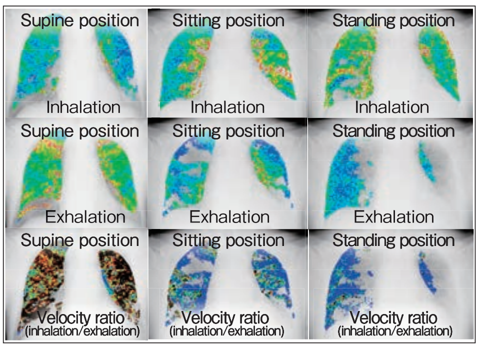

Fig. 3 Case 1: Interstitial Pneumonia. Airflow velocity analysis image during deep breathing

Interstitial Pneumonia

Case 1 was a 77-year-old male with idiopathic interstitial pneumonia (IIP). Pulmonary function such as vital capacity (VC) are within normal ranges, and there is a slight decrease in lung diffusion capacity (DL_{CO}), but overall pulmonary function was considered as normal. Although there is no hypoxemia, serum markers for interstitial pneumonia are high.

Static chest radiography showed diffuse reticular shadows, ground-glass opacity, and slight ventilation defect in the left lung. CT showed diffuse reticular shadows on the pleura side with emphysema and many ground-glass opacities. It was considered to be the case classified to Alternative Diagnosis (A shadow that could also be taken as a predominant cyst/ground-glass shadow) of ATS/ERS/JRS/ALAT International Diagnosis Guideline[1] rather than IIP.

Ventilation evaluation by DDR showed that the ventilation of the left lung reduced, but the lesion in the lower lobe was not so severe, and there was almost no differences between patient's posture **(Fig. 1)**. Next, in the airflow velocity analysis image by DDR, the expiration velocity, the inspiration velocity, and the velocity ratio (inhalation/

exhalation) were color-coded and displayed superimposed on the image. Red (high velocity) to blue (low velocity) was set according to the velocity, and the velocity ratio was set to red/black (high velocity) to blue (low velocity). Data missing parts were blank. In this case, the velocity ratio during tidal breathing was higher in the supine position than in the standing position **(Fig. 2)**, and even higher during deep breathing **(Fig. 3)**.

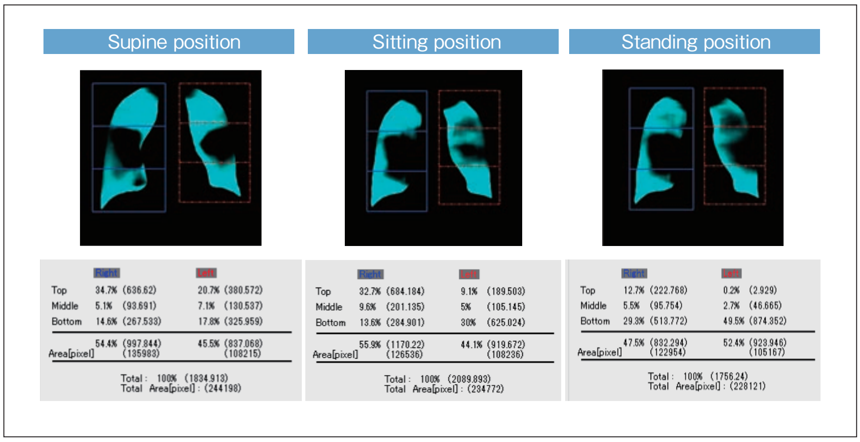

Fig. 4 Case 2 : Emphysema. Ventilation evaluation image

Emphysema

Case 2 was a 64-year-old male with emphysema developing giant bullae. He had a history of repeated pneumothorax, and resection and suturing of bullae was performed on the left side in 2001 and on the right side in 2008. After that, he became aware of the worsening of dyspnea around 2017, and in 2019, his exacerbation of dyspnea and emphysematous change became prominent, and he was referred to our department. For evaluation, DDR was performed.

Static chest radiography showed giant bullae and hyperpermeability, especially in the bilateral middle lung. The pulmonary function test showed obstructive ventilatory defect, and the flow volume curve showed a typical obstructive disorder pattern. CT showed marked emphysematous change in the upper lobe, giant bullae on both sides in the middle and lower lobes, and emphysematous change in the lower lobe.

Ventilation evaluation based on DDR showed that the ventilation volume decreased, especially according to the mid-lung bullae **(Fig. 4).** Airflow velocity analysis images did not show an increase in velocity ratio due to patient posture during tidal breathing **(Fig. 5)**, but showed a decrease in velocity during deep breathing **(Fig. 6)**, which appeared to be different from interstitial pneumonia.

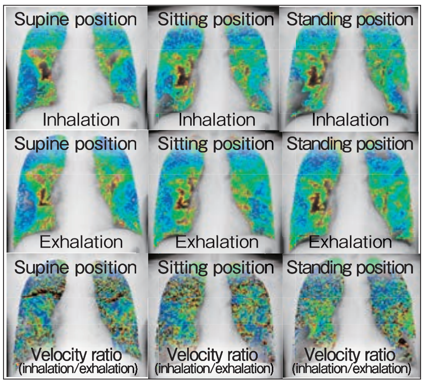

Fig. 5 Case 2: Emphysema. Airflow velocity analysis image during tidal breathing

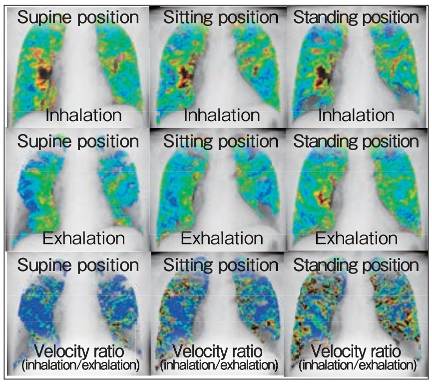

Fig. 6 Case 2: Emphysema. Airflow velocity analysis image during deep breathing

Conclusion

At our institution, DDR has been used to evaluate a regional ventilation/perfusion in chronic respiratory diseases, especially chronic obstructive pulmonary disease (COPD) and interstitial pneumonia. With the expectation that various parameters, that are useful for evaluating disease states and progression, would be obtained, we have begun accumulating various cases. In the future, we would like to evaluate the relationship of these data with various information and test results at the time of admission to hospital, or new biomarkers, as well as the relationship with disease progression.

● References

1) Raghu, G., et al., *Am. J. Respir. Crit. Care Med.*, 198(5): e44-e68, 2018.

Interstitial disease movement

Masakuni Ueyama, MD Department of Respiratory Medicine, Tenri Hospital

In this presentation, we report the usefulness of Dynamic Digital Radiography (DDR) in interstitial pneumonia (IP) by presenting cases.

Case 1: IP predominantly in the lower lung field

Case 1 is a 68-year-old female with IP predominantly in the lower lung field. A cough developed in September 2018. An IP was pointed out by a another physician nearby on December, and she visited our department on January 2019. Currently, being followed-up without any treatment. A former smoker (20 pieces/day × 30 years) with a history of renal disease, appendicitis, uterine adnexitis, and phlebangioma. The results of the blood test were antinuclear antibody (ANA): 640-fold, anticentromere antibody: positive, KL-6: 1,082 U/mL, SP-D: 362.1 ng/mL. According to the results of the pulmonary function test, the vital capacity (VC) was 2.19L(88.2% as percent predicted), and the lung diffusion capacity (% DL_{CO}) was 71.9% as percent predicted.

Static chest radiography showed reticular shadows and ground-glass opacities predominantly in the lower lung field. On CT image **(Fig. 1),** in the lower lung field, reticular and ground-glass shadows were observed from around the bronchial vessels to the subpleura, though there was not as much shadow as the upper lung field, suggesting a collagen disease lung. The DDR image **(Fig. 2)** showed that the movement of the lower lung field and the width of the rib cage was worse than in the normal case. In

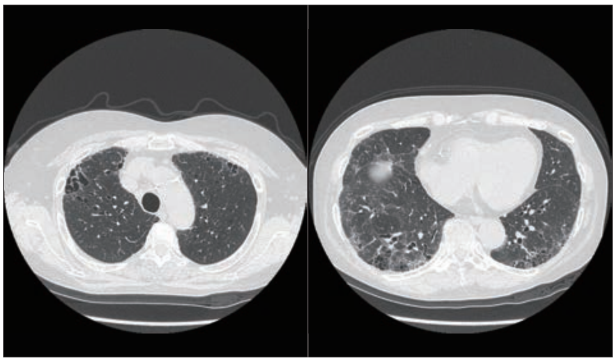

Fig. 1 Case 1: CT image

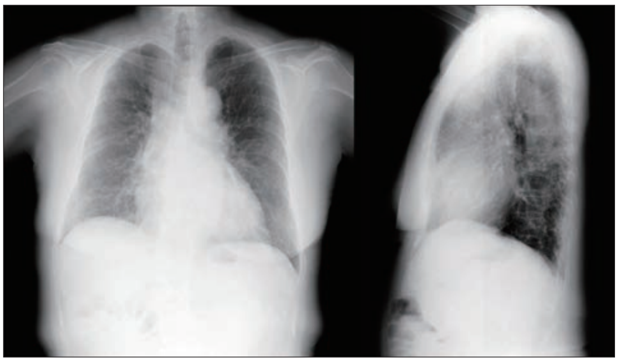

Fig. 2 Case 1: DDR image (PA and Lateral)

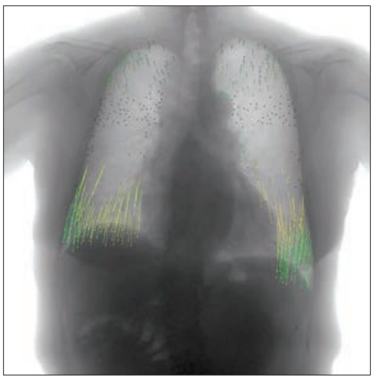

Fig. 3 Case 1: Motion vector-map

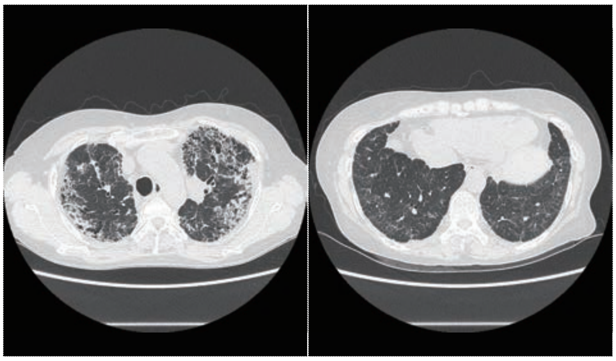

Fig. 4 Case 2: CT image

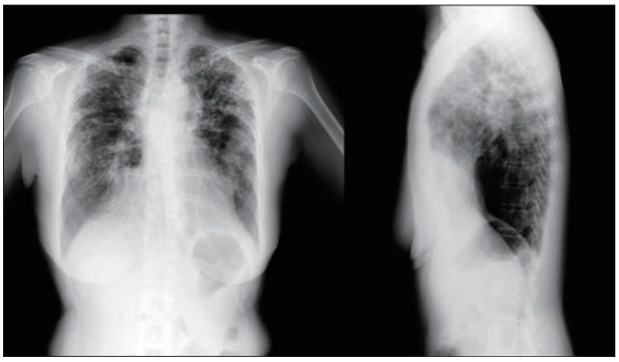

Fig. 5 Case 2: DDR image (PA and Lateral)

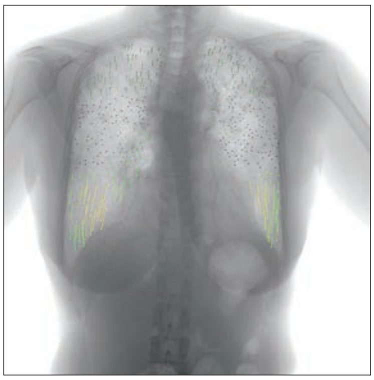

Fig. 6 Case 2: Motion vector-map

addition, it seemed that the movement of lower lung field is worse than normal control case based on a motion vector-map **(Fig. 3)** created from DDR image.

Case 2: IP predominantly in the upper lung field

Case 2 was a 65-year-old female with IP predominantly in the upper lung field. The main complaint was paroxysmal dyspnea on exercise (DOE). An abnormal finding was pointed out on static chest radiography in a annual health check-up for the first time in 2001, and an abnormal condition was pointed out again in a 2012 health check-up, thus the patient visited the previous doctor. The DOE appeared around July 2017, and she visited our department in February 2018 and underwent cryobiopsy. She was a nonsmoker with a history of childhood asthma, appendicitis, and fibroids. No serologically predominant positive findings were found, with KL-6: 739 U/mL and SP-D: 829.5 ng/mL. The results of the pulmonary function test were VC (%VC): 1.91 L (74%) and %DL$_{CO}$: 63.1%.
Static chest radiography showed reticular shadows and infiltration shadows predominantly in the upper lung field. CT image **(Fig. 4)** showed strong reticular shadows and consolidation in the upper lung field. DDR image **(Fig. 5)** showed that the movement was generally poor and the movement of the diaphragm is abnormal, and lateral DDR image showed the impression that the lower lobe of the lung mainly contributed to breathing. Even in the vector-map **(Fig. 6)**, the movement of the entire lung field seemed to be poor.

DDR for IP : Current status and future issues

In our hospital, IP-focused DDR has been performed, and data on 30 to 40 cases have been obtained so far. In all cases, PA and a Lateral DDR image were taken, and when the estimated lung volume obtained from those images was compared with the results of pulmonary function test, a good correlation was obtained. At present, there was only one stable case followed-up, and similar results were obtained in comparison of the past and present image. The follow-up of deteriorated cases, correlation with prognosis, and detection accuracy will be examined in the future.
In addition, as a feature of movement in IP, there is an impression that lower lung field movement and thorax cage movement are poor in patients with IP predominantly in the lower lung field, and that overall movement is poor in patients with IP predominantly in the upper lung field. In all patients, the movement of the thorax cage is better in the upper part than in the lower part. Although we have not yet performed a quantitative analysis of these, we would like to examine the differences in movement between IP subtypes in the future.

Evaluation of pulmonary circulation by Dynamic Digital Radiography

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In this presentation, I present pulmonary circulation imaging by Dynamic Digital Radiography (DDR) on two patients.

Case 1: Chronic thromboembolic pulmonary hypertension (CTEPH)

Case 1 was a 69-year-old female. Around January 2019, she visited another hospital with a complaint of shortness of breath during exercise, and was diagnosed with pulmonary embolism (PE). Anticoagulant therapy was performed, but the symptoms remained and chronicity was suspected. Therefore, DDR was performed at our hospital.

Static chest radiography **(Fig. 1a)** showed no obvious abnormalities, but x-ray pulmonary circulation image by DDR **(Fig. 1b)** revealed multiple segmental defects in both lung fields. ^{99m}Tc-MAA pulmonary perfusion scintigraphy **(Fig. 1c)** showed frequent segmental defects, which is a characteristic of CTEPH, and this finding was consistent with pulmonary circulation image by DDR. Similar findings were found in iodine map of the contrast CT **(Fig. 1d)**. As a result of right heart catheterization, the mean pulmonary artery pressure was 43 mmHg, and the patient was diagnosed with CTEPH. Pulmonary hypertension (PH) is classified into five types such as (1) Pulmonary arterial hypertension (PAH), (2) PH due to left heart disease, (3) PH due to lung disease and/or hypoxemia, (4) CTEPH, and (5) PH due to unknown cause and/or complex factors, and these are differentiated in diagnosis.

CTEPH is defined as the state having an organized thrombus in the pulmonary artery that does not dissolve with anticoagulant therapy for 6 months or more, and the mean pulmonary artery pressure is ≥25 mmHg (normal value <20 mmHg). It has two aspects, PH and PE, and may be found triggered by PH without any apparent history of PE.

The recently proposed algorithm for the diagnosis of PH[1] emphasized that early screening of CTEPH by pulmonary ventilation/perfusion scintigraphy was important. However, we consider the possibility that pulmonary perfusion image by DDR can be used as the screening test

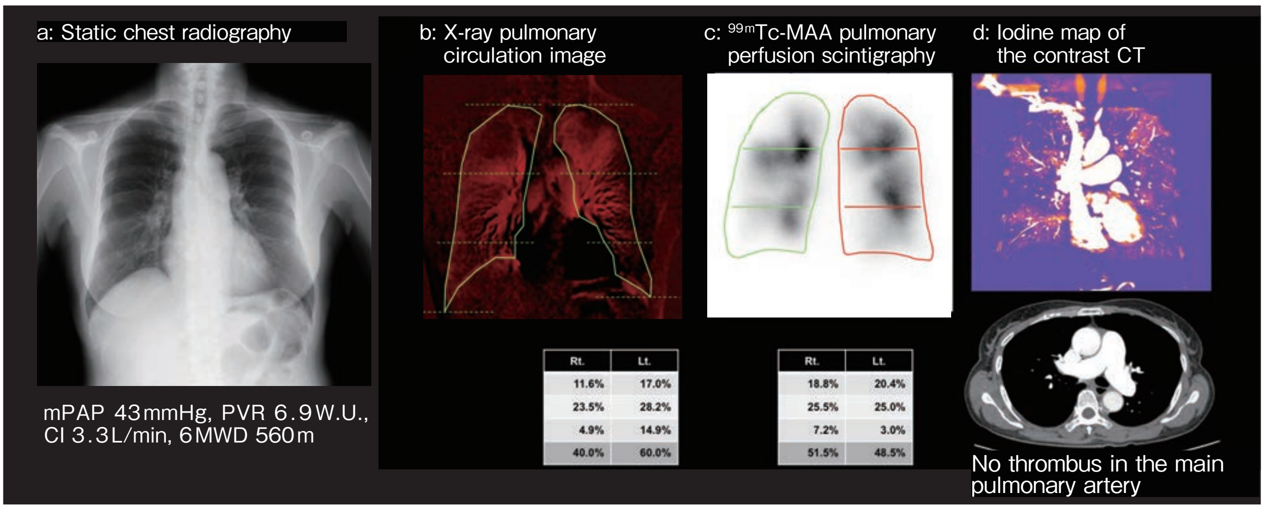

Fig. 1 Case 1: Chronic thromboembolic pulmonary hypertension (CTEPH)

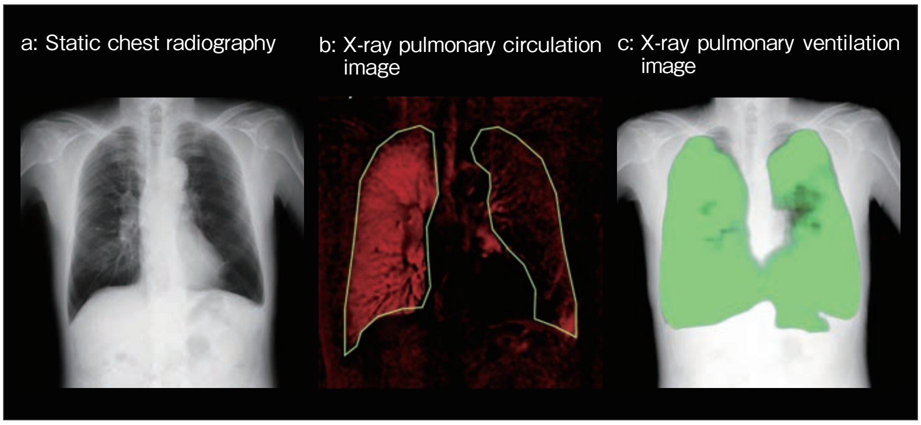

Fig. 2 Case 2: Giant cell arteritis, severe left pulmonary artery stenosis

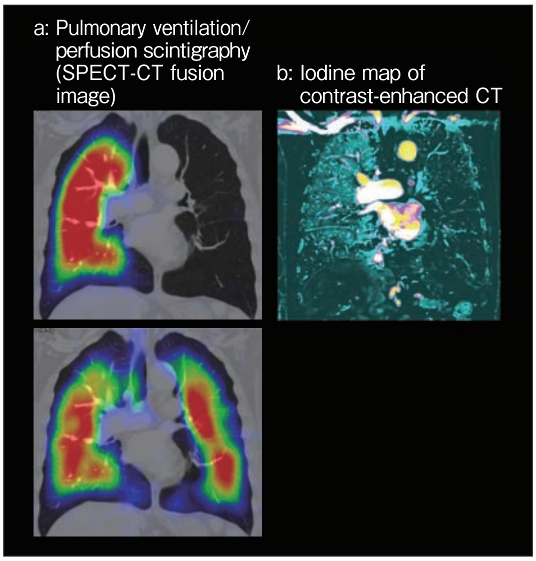

Fig. 3 Ventilation/perfusion scintigraphy and Iodine map of contrast-enhanced CT in Case 2

before pulmonary ventilation/perfusion scintigraph in the future.

Comparison of pre- and postoperative pulmonary artery angiography with circulation image by DDR in another patient with CTEPH also showed that pulmonary circulation was restored after surgery. Thus, x-ray pulmonary circulation image by DDR was also expected to be used for evaluation of pulmonary circulation before/after treatment.

Case 2: Giant cell arteritis, severe left pulmonary artery stenosis

Case 2 was a 74-year-old male. He visited a previous physician complaining of dyspnea and cough, and diagnosed as having pneumonia. The symptoms remained even after antibiotic treatment, so DDR was performed at our hospital. On static chest radiography **(Fig. 2a),** the right pulmonary vasculature was dilated while the left pulmonary vasculature was less visible. The x-ray pulmonary circulation image by DDR **(Fig. 2b)** shows that the circulation in the left lung is extremely poor. On the other hand, x-ray pulmonary ventilation image by DDR **(Fig. 2c)** showed that both lungs were uniformly ventilated. Similar findings were obtained on pulmonary ventilation/perfusion scintigraphy and iodine map of contrast-enhanced CT **(Fig. 3)**. Contrast-enhanced CT showed that the main trunk of the left pulmonary artery was highly narrowed and soft shadows were widespread around it. Depiction of left pulmonary vessels was poor in 3D pulmonary artery images. FDG-PET/CT showed a high accumulation of SUVmax = 7.6, which was consistent with the soft shadow of contrast-enhanced CT. Based on these results, we diagnosed severe left pulmonary artery stenosis due to giant cell arteritis.

By performing DDR, pulmonary ventilation/perfusion information can be easily obtained, and it is considered to be useful even in situations where contrast-enhanced CT and scintigraphy cannot be used easily.

● References

1) Frost, A., et al.: Diagnosis of pulmonary hypertension. *Eur. Respir. J.*, 53 (1): 1801904, 2019.

Executive Remark

Shoji Kudoh, MD, PhD
Chairman, Board of Directors, Japan Anti-Tuberculosis Association /
Professor Emeritus, Nippon Medical School Foundation

I was amazed that there was a great progress in the research for just one year since the first Dynamic Digital Radiography Seminar in 2018. I would like to express my sincere respect to the researchers who have conducted research throughout Japan.

I would like to mention three things that were particularly impressive through today's presentation and discussion. First, I felt that the possibility of realizing visualization of ventilation and perfusion by separating ventilation related signal and perfusion related signal, which was beginning of the development of Dynamic Digital Radiography (DDR), and detection of pulmonary thromboembolism has increased. Compared with ventilation and perfusion scintigraphy, although each modality has its own characteristics, there may be a possibility that DDR image would be equivalent to those, or could be used instead. Above all, it could be widely used in clinical practice because the examination cost is lower and it could be performed in small - medium hospitals. Although there are some issues, there are some reports that they are on par with ventilation and perfusion scintigraphy, and further research is expected.

Second, I felt the spread of applications. At the beginning of the development of DDR, target diseases which came to mind, were a few such as chronic obstructive pulmonary disease (COPD) and interstitial pneumonia. However, this time, there were clinical case presentations of application to various diseases such as alveolar hypoventilation syndrome and chronic thromboembolic pulmonary hypertension, and studies on the relationship with diaphragm pacing were also reported. I felt that the spread of applications was very fresh and important.

Third, new points of interest have been raised, such as the change rate in lung area, tracheal diameter, and posterior ribs. In the "Atlas Concept of Movement" introduced in the manufacturer's report, we received an important message that "dynamic images have a large number of landmarks in the lung thorax". As for what we should pay attention to, I think that the researchers who are interested will work on each of them, but it is important that there are so many landmarks. I recall the textbook "Felson's Principles of Chest Roentgenology", by which I first studied static chest radiography. The first edition was issued in 1965, and 70 years have passed since the discovery of x-rays in 1895, and finally a "silhouette sign" was raised. With that in mind, I feel that having many landmarks was like having a treasure mountain in front of you, and that there might be a possibility of new discoveries over time.

Currently, DDR has been introduced to 17 facilities nationwide. We believe that a DDR, that has the advantage of being able to conduct examination in small and medium hospitals, should ultimately aim for insurance coverage in Japan, but it is also expected to be deployed in developing countries such as the Asian region. DDR could be used in developing countries where scintigraphy is not readily available. In terms of easy-to-perform, even in recent frequently occurring disasters such as earthquakes and floods, there is a possibility that economy-class syndrome can be easily screened in the evacuation centers, and its use is expected to expand in the future. I can't imagine what presentation will be coming in the next seminar or later, but I'm really looking forward to them.

The 2nd Dynamic Digital Radiography Seminar

Date: November 2, 2019 (Sat)

Venue: Fukuracia Yaesu Conference Room A

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Atsuko Kurosaki, MD, PhD
(Fukujuji Hospital, Japan Anti-Tuberculosis Association)

Part 2 Chair:
Kazuo Kasahara, MD, PhD
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Part 3 Chair:
Terumitsu Hasebe, MD, PhD
(Tokai University)