The 3rd Dynamic Digital Radiography Seminar

Date and time：13:00 to 17:00, Saturday, June 5, 2021

Venue：Online

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CONTENTS

KONICA MINOLTA JAPAN, INC.

Opening Remarks

Hiroto Hatabu, MD, PhD, FACR Professor of Radiology, Harvard Medical School

Dynamic Digital Radiography technology is based on the research of Dr. Shigeru Sanada (currently at Komatsu University) and Dr. Rie Tanaka at Kanazawa University. Over the past 15 years, Konica Minolta has developed this technology together with Dr. Shoji Kudo, President of Japan Anti-Tuberculosis Association, who is one of the world' s leading experts on respiratory and physiology. I myself joined the research project of Dynamic Digital Radiography in 2014.

In 2016, Dr. Yoshitake Yamada of Keio University and Dr. Rie Tanaka of Kanazawa University presented their research results at the Radiological Society of North America (RSNA 2016) and received Magna Cum Laude awards, which brought Dynamic Digital Radiography to worldwide attention.

Now, the research on Dynamic Digital Radiography has been rapidly expanded. In the morning session of the Fleischner Society Endorsed Educational Seminar held on November 3, 2020, Dr. Shoji Kudo gave the keynote lecture titled "Expectation for Chest Dynamic X-ray (DXR)," and Dr. Tomoyuki Hida of Kyushu University presented the results of his research, focusing the diaphragm motion, titled "Clinical applications of Chest Dynamic X-ray (DXR)."

Recently, Dr. Akinori Hata of Osaka University published a review of Dynamic Digital Radiography in *Korean Journal of Radiology* titled "Dynamic Chest X-Ray Using a Flat-Panel Detector System: Technique and Applications" based on the presentation by Dr. Yamada at RSNA 2016.

In addition, Dr. Takuya Hino of Kyushu University has been working on Vector-Field Dynamic X-ray (VF-DXR) and summarized his results in "Vector-Field Dynamic X-ray (VF-DXR) using Optical Flow Method" which was in press in *The British Journal of Radiology*. Dr. Takuya Hino also presented "Projected lung areas using dynamic X-ray (DXR)" in *European Journal of Radiology Open*. This study investigated the possibility of obtaining information similar to that obtained with pulmonary function test by capturing changes in lung field area over time.

As seen from the above, Dynamic Digital Radiography has been established as a new imaging morality by academia, clinicians and industry after many years. I am very honored to have been able to work with them for more than 6 years. In this seminar, there will be many presentations on a wide range of topics from all over Japan, and I hope that there would be fruitful discussions. I hope that you would create a "new page of the future" with yours.

The 3rd Dynamic Digital Radiography Seminar

Date and time: June 5, 2021 (Saturday) 13:00-17:00

Venue: Online

Chairperson:

Part 1: Terumitsu Hasebe, M.D., Ph.D. (Department of Radiology,Tokai University School of Medicine)

Part 2: Kei Takase, M.D., Ph.D. (Diagnostic Radiology, Tohoku University School of Medicine)

Part 3: Atsuko Kurosaki, M.D., Ph.D. (Department of Diagnostic Radiology, Fukujuji Hospital, Japan Anti-Tuberculosis Association)

Part 1:
Technology / Thoracic Surgery

Part 2:
Pulmonary Circulation

Part 3:
Pulmonary Function

Reproducibility of Respiratory Motion in Chest Dynamic Digital Radiography

Daigo Kuroda Department of Radiology, Tenri Hospital

In June 2019, we started the clinical study of chest Dynamic Digital Radiography (cDDR) for patients with interstitial pneumonia (IP). We experienced a case in which a different respiratory motion image from previous one was obtained in a follow-up case. We will introduce the verification of reproducibility of the respiratory motion.

Verification of reproducibility of respiratory motion in cDDR

In order to eliminate the variation in the imaging protocol of cDDR among x-ray technologists, we have been using the audio guide. However, when multiple examinations are performed, it is thought that there are cases in which the respiratory motion are not stable for each examination.

In order to verify the reproducibility of respiratory motion in cDDR, we examined 46 images of 15 patients (average age: 70.8 y.o.) who had undergone cDDR more than three times at our hospital, to check (1) whether they were able to breathe following the audio guide and (2) whether image acquisition can be done with maximum exhalation and inhalation.

At first, the exhalation time (from maximum inhalation to maximum exhalation) and the inhalation time (from maximum exhalation to maximum inhalation) were calculated from the number of frames of cDDR images and compared with the instruction time of the audio guide. As a result, 15 cases of exhalation time and 38 cases of inhalation time deviated from the instruction time of the audio guide (5 seconds) by 1 second. The data for all patients showed that the inhalation time was short and varied widely.

Furthermore, the relationship between % forced vital capacity (%FVC), an indicator of worsening respiratory status, and inhala-

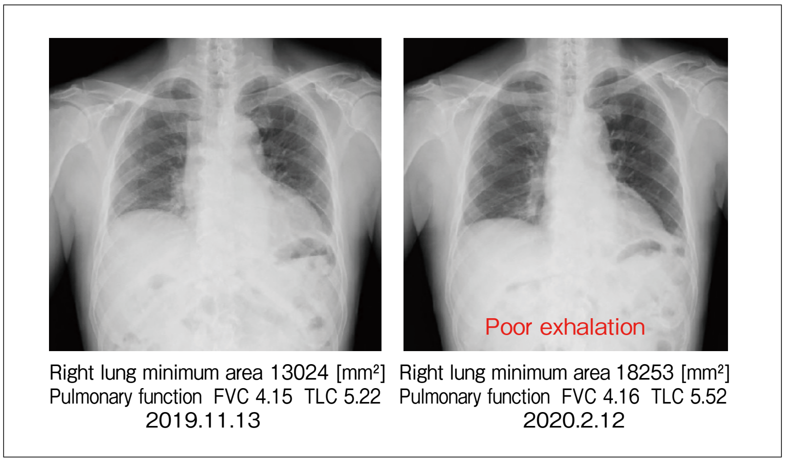


Fig. 1 Case 1: cDDR image at maximum exhalation

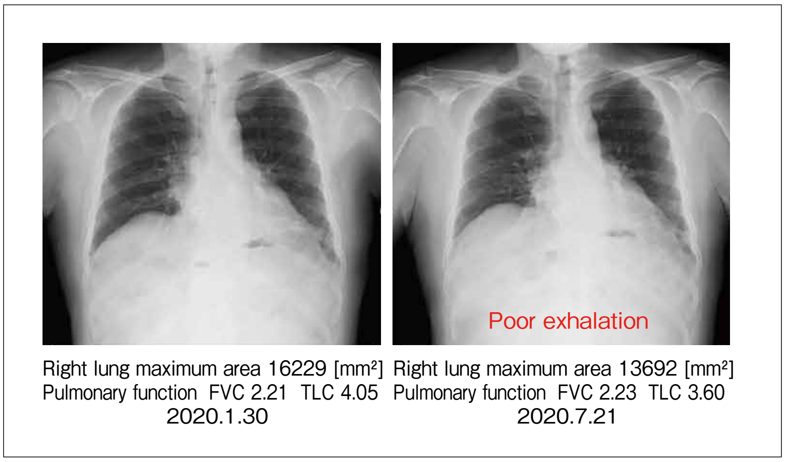
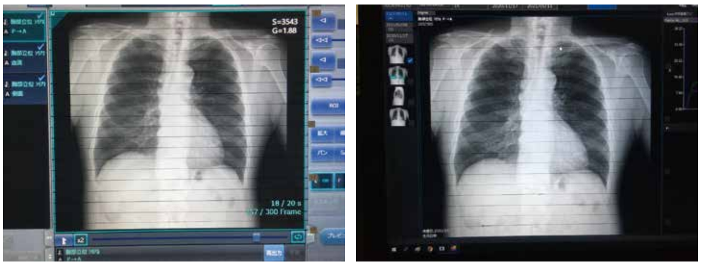


Fig. 2 Case 2: cDDR image at maximum inhalation

tion time was shown to be low. The discrepancy in respiratory time was not due to a respiratory condition such as difficulty in breathing, but due to a lack of understanding of the way to breath during cDDR. In addition, the lung field area during maximum exhalation and inhalation at multiple examinations was measured respectively and evaluated using the coefficient of variation. The results indicated that the variation at maximum exhalation was large. In comparison with the coefficients of variation of FVC and total lung capacity (TLC) of pulmonary function tests performed on the same day, cDDR was more variable and less reproducible than the pulmonary function tests.

Grid line display using unexposed loss films

Fig. 3 How we check images at our hospital



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Reproducibility is confirmed by displaying grid lines corresponding to the display of each terminal.

Fig. 4 Confirmation of reproducibility

Case Presentation

The following are actual cases. In case 1, the values of pulmonary function tests were almost unchanged at each examination, but the lung field area at maximum exhalation differed greatly, and the difference was visible on the images (**Fig. 1**). At the time of this image aquisition, we were inexperienced in cDDR acquisition at our hospital, and it would have been possible to retake the images if a reliable comparison had been made with the previous images.

In case 2, as in case 1, there was no significant difference in pulmonary function tesets, but the patient had poor exhalation at the first image acquisition and poor inhalation at the second aquisition (**Fig. 2**). The percentage of change in lung field area during maximum exhalation and inhalation was not significantly different between the two imaging acquisitions. This would indicate that it is difficult to determine inhalation and exhalation in this case unless the differences in the images are confirmed.

Efforts to improve the reproducibility of Dynamic Digital Radiography

In our hospital, we gave a standardized explanation to the patients before the imaging aquisition. However, based on these results, we are trying to provide detailed explanations according to the patient's level of understanding, and we are also paying attention to advance practice, such as repeated practice using the audio guide, or for x-ray technologist to give supportive voice over the practice with audio guide. Furthermore, we have made efforts to improve as follows: To display cDDR images immediately after imaging on the Konica Minolta “CS-7H console,” and display the past images on the imaging workstation “KINOSIS,” and superimpose the unexposed loss films with grid lines drawn on each flims, then to check the diaphragmatic level of maximum inhalation and exhalation by referring to the grid lines while playing back cDDR image. So, we are now able to make appropriate decisions on whether to repeat the imaging in addition to improving the reproducibility of cDDR (**Figs. 3 and 4**). In the future, we will increase the number of cases and continue our study.

Preoperative Evaluation of Pleural Adhesion in Thoracic Surgery: Comparison of chest Dynamic Digital Ragiography and surgical findings

Motofumi Ohuchi, MD, PhD Department of Thoracic Surgery, Seirei Yokohama General Hospital

Our hospital is a medium-size hospital having 370 beds located in the center of Yokohama City. In the Department of Respiratory Surgery, many inflammatory diseases such as pulmonary aspergillosis and nontuberculous mycobacteriosis are treated, and the degree of adhesions and lung cancer invasion associated with inflammatory diseases has a significant impact on the time and preparation for surgery. We will report a study on the usefulness of chest Dynamic Digital Radiography(cDDR) for preoperative evaluation of pleural adhesion in respiratory surgery.

Comparison of preoperative evaluation and intraoperative findings by c DDR

The subjects were 29 patients who underwent lobectomy or more serious surgeries at our hospital between July 2020 and April 2021 and underwent preoperative cDDR. Among them, 17 patients had lung cancer, 3 had pulmonary aspergillosis, 4 had nontuberculous mycobacteria, 1 had giant pulmonary cystosis, and 4 had other diseases. We compared the findings of cDDR and intraoperative findings in 7 cases of inflammatory disease (3 cases of pulmonary aspergillosis and 4 cases of nontuberculous mycobacteriosis), 5 cases of lung cancer, and 1 case of giant pulmonary cystosis, in which pleural adhesions were expected.

In preoperative cDDR, BSxFE-MODE (bone suppression processing & frequency enhancement processing) was used to determine adhesions based on the movement of blood vessels and chest wall. The criteria for adhesion grading were 0 for no adhesions, 1 for fibrous adhesions without surgical impact, 2 for partial but strong adhesions, and 3 for strong adhesions in the entire lung field. The results of the comparison of preoperative evaluation and intraoperative findings are shown in **Table 1**. In lung cancer, the accuracy of preoperative evaluation was 94.1% (16/17 cases), and grade 3 adhesions were missed in one case. In pulmonary aspergillosis, the accuracy of preoperative evaluation rate was 66.7% (2/3

Table 1 Intraoperative evaluation of pleural adhesions

Grade	0: No adhesions (Number of preoperative cases/ correct response rate)	1: Band adhesions without surgical failure	2: Partial firm adhesions	3: Firm adhesions in the entire lung field
Lung cancer	12 (0)	4 (−1)	0	1 (+1)
Lung aspergillosis	0	0	3 (+1)	0 (−1)
Nontuberculous mycobacteriosis	0	4 (+2)	0 (−2)	0
Giant pulmonary cystosis, etc.	4	1	0	0

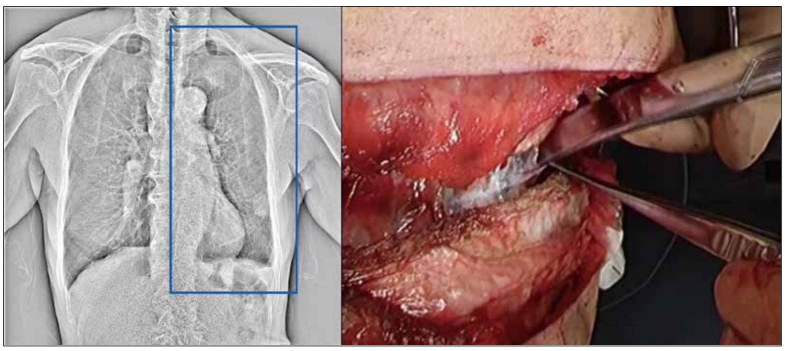

Fig. 1 Case 1: Lung cancer case (with history of COPD)

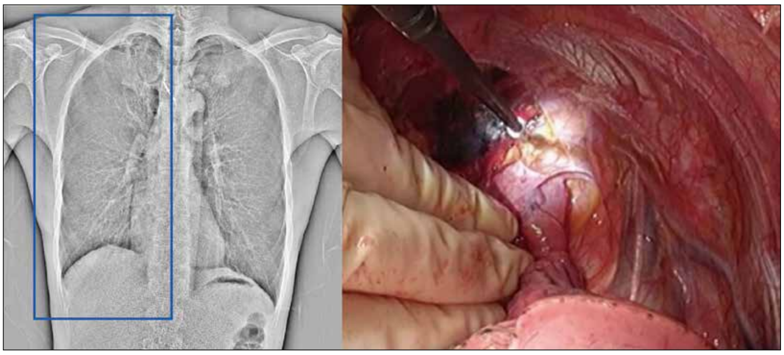

Fig. 2 Case 2: Nontuberculous mycobacteriosis case

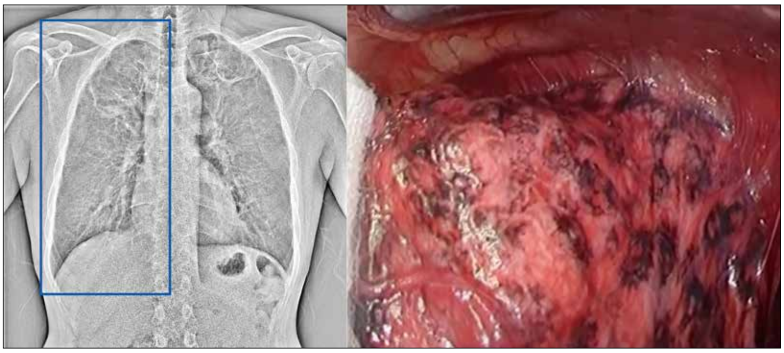

Fig. 3 Case 3: Pulmonary aspergillosis case

cases), and one case rated as grade 3 was actually grade 2. In nontuberculous mycobacteriosis, the accuracy of preoperative evaluation rate was 50.0% (2/4 cases), and 2 cases rated as grade 2 were actually grade 1. In giant pulmonary cystosis or others, the accuracy of preoperative evaluation was 100% (5/5 cases).

Case Presentation

Case 1: Lung cancer patient (with a history of chronic obstructive pulmonary disease) (Fig. 1)

The patient was a 77 y.o. male with lung cancer, who had a history of chronic obstructive pulmonary disease (COPD) and was receiving inhalation therapy. In the preoperative BSxFE-MODE evaluation, there was respiratory-related motion in the tumor location and in the vascular shadows throughout the lung field. Thoracoscopic surgery was started, but it was switched to thoracotomy because of adhesions. Although the adhesions involved the entire lung field, they were mild fibrous adhesions that were easily peeled off.

Case 2: Nontuberculous mycobacteriosis (Fig. 2)

This 49 y.o. male patient was referred to our hospital because hemoptysis occurred after 6 years without treatment following diagnosis of nontuberculous mycobacteriosis. In the preoperative BSxFE-MODE evaluation, we suspected adhesion because of the small motion in the upper lung field, but we expected minor adhesion because there was not a clear difference from the healthy-side lung. However, the intraoperative findings showed that there was strong adhesion partially at the apex of the lung, and extrapleural dissection was performed.

Case 3: Pulmonary aspergillosis (Fig. 3)

The patient was a 54 y.o. male who had received chemotherapy for pulmonary tuberculosis for 6 months 2 years before, and was infected with aspergillus in the remaining cavity. The preoperative BSxFE-MODE evaluation showed that the upper lung fields were almost completely fixed, and we expected that there were strong adhesions. During the operation, there were strong adhesions in the upper lung area of the lesion area, and an extrapleural dissection with electrocautery was performed. Based on the history of pulmonary tuberculosis, we empirically assumed that the adhesions were circumferential, but only minor fibrous adhesions were observed outside the lesion area.

Summary

In this study, we conducted a comprehensive preoperative evaluation based on the findings of conventional radiographs (static image), CT, empirical judgment for each disease, and cDDR. The apex of the lung does not move much even in healthy subjects, and it is difficult to determine the apex of the lung by BSxFE-MODE evaluation, and no clear prediction method has been found at present. We would like to refer to a report[1] from another hospital that prediction of adhesions with a sensitivity of 95% and specificity of 96% was possible by assessing risk factors based on FE-MODE findings. In the future, we plan to study the new mode for adhesion evaluation (LM-MODE) installed in the new product of Konica Minolta and objective evaluation using target sites such as tumors and blood vessels.

●References
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Dynamic Digital Radiography in thoracic surgery: Our experience and expectations for future development

Haruhiko Kondoh, MD, PhD Department of Thoracic and Thyroid Surgery, Faculty of Medicine, Kyorin University

In June 2020, Dynamic Digital Radiography from Konica Minolta was installed in our hospital as part of a renewal of conventional radiography equipment. In this presentation, we will describe our experience using the chest Dynamic Digital Radiography(cDDR) in respiratory surgery and our expectations for the future development.

Items to consider in Respiratory Surgery

In our department, at first, we examined usefulness as preoperative imaging modality, optimal imaging conditions, usefulness in confirming postoperative recovery and complications, and depiction of specific pathologies using actual cDDR images.

In addition, we are currently conducting retrospective and prospective studies. Specifically, as information that cannot be obtained from conventional chest radiographs (static image), we are conducting evaluation of improved visibility of pulmonary nodules, changes in the position of each organ due to body position and posture, changes in diaphragmatic motion due to respiration (pre- and postoperative evaluation), presence and degree of intrathoracic adhesions, noninvasive observation of vocal cord paralysis, pulmonary collapse in pneumothorax cases, improvement of ventilation by airway stents, etc. Some of these clinical cases will be presented below.

Practical clinical experience in our department

1. Detection of lung nodules

During detecting pulmonary nodules, the nodule shadow may not be clearly visible in static images due to overlap with vascular and mediastinal shadows, nipples, clavicles, ribs, and diaphragm. As an example, upon checking cDDR images of a shadow that was difficult to distinguish from a nipple with a static image, we were able to clearly diagnose it as a micro nodule in S^8 of the lower lobe of the right lung. In another case **(Fig. 1)**, the shadow in the left upper lung field pointed out in static image was clearly identified as an intrapulmonary nodule on the dynamic x-ray image, and the lesion was more clearly delineated by BSxFE-MODE (bone suppression processing & frequency enhancement processing).

Thus, the detectability of small and faint lesions can be improved by cDDR images, suggesting that it may be useful for the health checkup, screening and etc. Further verification will be conducted in the future.

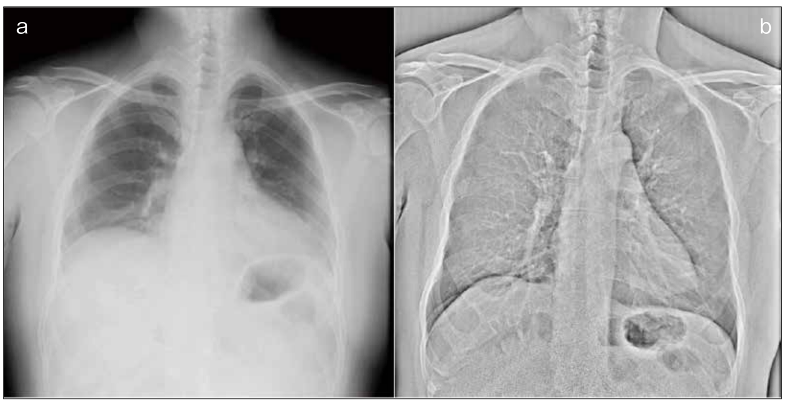

Fig. 1 Lung nodule depiction by BSxFE-MODE
a: cDDR image　b: BSxFE-MODE

2. Evaluation of changes in position of each organ due to body position and posture

In the dynamic digital radiography images of the neck, it is clear that the trachea rises with dorsal flexion. Therefore, it is useful for preoperative evaluation of borderline lesions in the cervicothorax, such as mediastinal goiter, tracheal tumor, and tracheal stenosis.

Diaphragmatic motion and ventilatory status can also be visualized on cDDR. Decreased diaphragmatic motion and ventilation may be due to diaphragm laxity, neoplastic lesions, or transient postoperative decrease. Since it can be confirmed that diaphragmatic motion differs greatly between the upright and supine positions, we believe that cDDR image is one of the options for evaluating recovery from diaphragmatic paralysis.

Fig. 2 shows a case of left hilar tumor. The left bronchus was obstructed due to tumor infiltration, and the left diaphragmatic nerve was also paralyzed. FE-MODE showed that the mediastinum was displaced to the right due to air trap in the left lung during exhalation, and PL-MODE revealed that the ventilation of the left lung was greatly reduced.

In addition, we believe that cDDR images can be used to evaluate postoperative thoracic and diaphragmatic motions and the recovery process of blood circulation. In addition, it is possible to evaluate for vocal cord paralysis. In a case of lymph node metastasis from esophageal cancer, bilateral recurrent nerve palsy was found during follow-up after tracheal stent placement, and a tracheostomy was performed immediately.

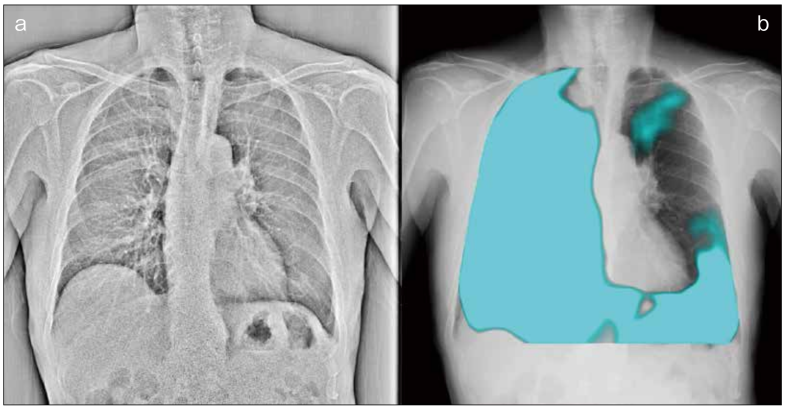

Fig. 2 Evaluation of poulmonary ventilation using PL-MODE
a: FE-MODE b: PL-MODE

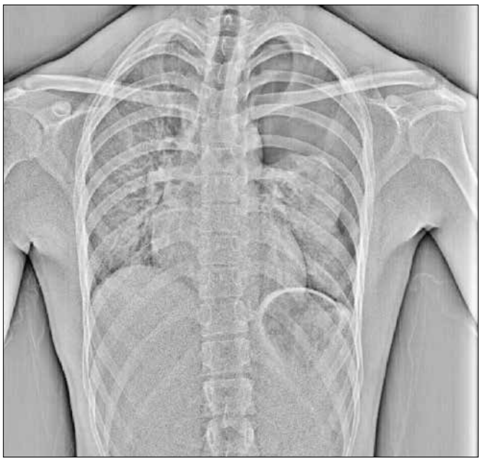

Fig. 3 Evaluation of pneumothorax severity using FE-MODE

3. Application to selection of the diagnosis and treatment method of pneumothorax

In the case of pneumothorax, we believe that cDDR images are useful for evaluating the severity of the disease and selecting a treatment method. **Fig. 3** shows a case of pneumothorax in the left lung. Although the collapse of the lung was thought to be mild in the conventional chest radiography, the FE-MODE image showed a large atrophy of the lung.

Expectations for dynamic x-ray image

The history of x-rays began with their discovery by Roentgen in 1895, followed by various developments in the diagnosis of conventional chest radiography, and progress to digitalization in the 1980s. Since the 2000s, little progress has been made in the diagnostics and diagnostic performance of conventional radiographs, but now, cDDR have emerged. cDDR are expected to be able to observe the physiological condition, to evaluate the functional status, and to have less radiation exposure than CT.

Clinical application of pulmonary circulation imaging by Dynamic Digital Ragiography

Yuzo Yamasaki, MD, PhD Department of Clinical Radiology, Graduate School of Medical Sciences, Kyushu University

In this presentation, I will introduce the usefulness of pulmonary circulation imaging by chest Dynamic Digital Radiography(cDDR) with some case examples.

Radiology area [1]

In case 1, a 52 y.o. female patient was referred to our hospital for embolization after a pulmonary arteriovenous malformation (AVM) was diagnosed. At the time of admission, contrast-enhanced CT showed a nodule that enhanced to a circle of just over 2cm in diameter in S^3 of the right upper lobe, and showed continuity with the pulmonary artery and pulmonary vein. 3D imaging confirmed an AVM with one feeder and one drainage vein. Conventional chest radiographs showed a nodular shadow in the right upper lung field, and concurrent cDDR showed enhancement consistent with the nodule, with a continuous linear enhancement area caudally. Transcatheter embolization was performed, and posttreatment pulmonary angiography showed that the enhancement of the nidus and drainage vein disappeared.

In the conventional radiographs before and after the treatment, no obvious difference could be identified except for a slight decrease in the permeability of the nodules after embolization (**Fig. 1a**). In contrast, cDDR image shows that the enhancement of the nodules and drainage vein disappeared before and after treatment (**Fig. 1c**). This finding is in good agreement with the findings of pulmonary angiography (**Fig. 1b**), indicating that cDDR is useful for the evaluation of AVM before and after treatment.

Cardiology/respiratory medicine area [2]

In case 2, a 46 y.o. female and a 21 y.o. female were referred to our hospital for a thorough investigation of pulmonary hypertension. After admission, cardiac catheterization revealed pulmonary hypertension in both cases. Pulmonary hypertension is classified into five groups according to the cause, and classification is very important because treatment strategies differ. It is said that it is especially important to identify chronic thromboembolic pulmonary hypertension (CTEPH), whose prognosis has greatly improved with advances in treatment.

Although conventional radiographs show an enlarged heart in a 46 y.o. female and an enlarged pulmonary artery in a 21 y.o. female , it is difficult to estimate the cause of pulmonary hypertension. On the other hand, findings based on cDDR were clearly different between the two,

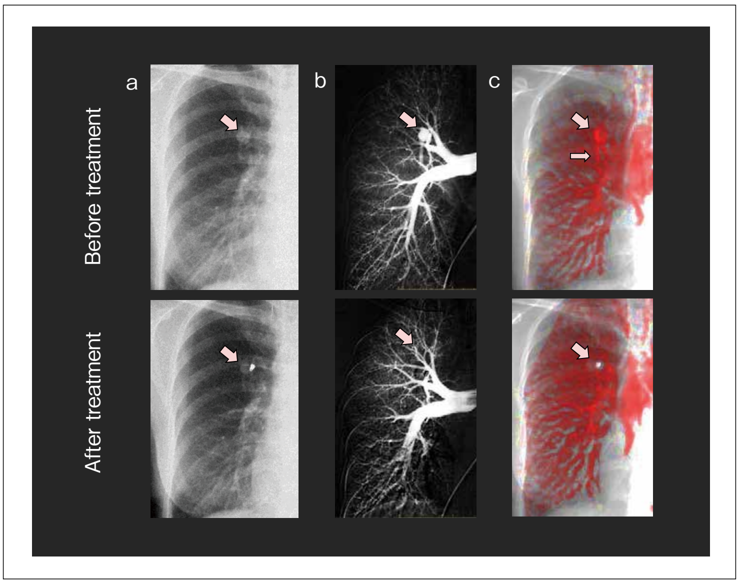

Fig. 1 Case 1: AVM

with multiple regional defects in the lung fields of the 46 y.o. female **(Fig. 2a)** and relatively uniform enhancement of the lung fields of the 21 y.o. female **(Fig. 2c)**. These findings were in excellent agreement with pulmonary perfusion scintigraphy **(Figs. 2b, d)**. Finally, a 46 y.o. female was diagnosed with CTEPH and a 21 y.o. female with pulmonary arterial hypertension(PAH), and cDDR was useful in finding the cause of pulmonary hypertension.

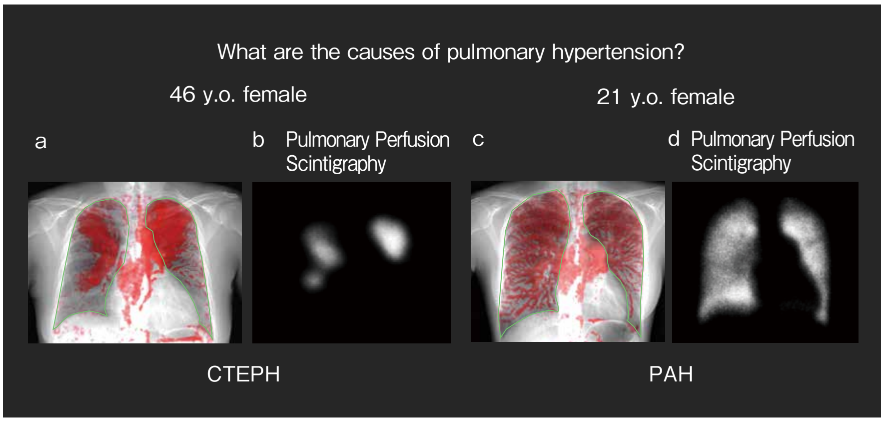

Fig. 2 Case 2: Pulmonary hypertension

Cardiac surgery areas [3)]

Case 3 is a 46 y.o. male who was diagnosed with CTEPH at another hospital and referred to our hospital for pulmonary artery thromboendarterectomy. Preoperative contrast-enhanced computed tomography (CT) showed multiple uneven thrombus and reticular thrombus in the right and left pulmonary arteries, right ventricular wall thickening, and uneven pulmonary venous return, but no obvious abnormality was noted in the pulmonary field, consistent with CTEPH. Pulmonary perfusion scintigraphy **(Fig. 3b)** showed segmental defects in the right lower and left middle lung fields, and pulmonary angiography showed similar findings.

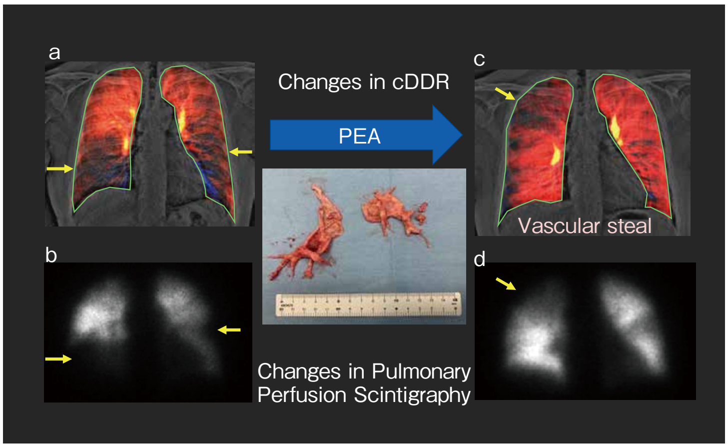

Fig. 3 Case 3: CTEPH

Pulmonary artery thromboendarterectomy (PEA) was performed and extensive thromboendothelium was removed from the right and left pulmonary arteries. Although conventional radiographs did not show clear differences between the pre- and postoperative periods, cDDR showed a significant improvement in blood circulation in the right lower lung field when compared before surgery and at 7 days after surgery **(Figs. 3a, c)**. It was also in good agreement with findings of pulmonary angiography and pulmonary perfusion scintigraphy **(Fig. 3d)**, indicating that cDDR was useful for postoperative evaluation of CTEPH. In addition, the postoperative decrease in blood circulation in the right upper lung field was considered to be a relatively still phenomenon due to the recovery of blood circulation in the right lower lung field.

Summary

cDDR has advantages such as being noninvasive and immediate, not requiring contrast media or radionuclides, low cost, and low radiation exposure. As shown in this report, cDDR can be used in various fields, and is useful for diagnosis and treatment because it provides a lot of information when added to conventional chest radiography. In some cases, it is possible to obtain information equivalent to contrast-enhanced CT or pulmonary perfusion scintigraphy, making it a very useful imaging modality that can be used as an alternative.

●References

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Diagnosis of acute pulmonary thromboembolism with Chest Dinamic Digital Radiography

Kazuya Hosokawa, MD, PhD Department of Cardiovascular Medicine, Kyushu University Hospital

We will report our investigation about the diagnostic performance of chest dynamic digital radiography(cDDR) in acute pulmonary emobolism (PE).

Algorithm for PE diagnosis and cDDR

The number of patients with PE has increased rapidly in Japan in recent years, and PE has become a frequently encountered disease in the daily practice of cardiology. It is a disease that has a high probability of death if untreated[1] and should not be missed. In the current diagnostic algorithm for PE, it is recommended to confirm symptoms and physical findings, check for the presence of elevated D-dimer, right ventricular load, and venous thrombus in the lower extremities, and finally make the diagnosis by contrast-enhanced CT.

On the other hand, PE is a major cause of death in pregnant and nursing women, and the risk of developing PE is reported to be 6 times higher in late pregnancy and 22 times higher in the early puerperium period.

In this context, a diagnostic algorithm for PE in pregnant and nursing women was proposed at the European Society of Cardiology 2019, and it was stated that pulmonary perfusion scintigraphy could be used instead of contrast-enhanced CT when conventional chest radiographs indicate normal. The advantage of pulmonary perfusion scintigraphy is that the radiation dose is reduced to about half for the fetus and about 1/20 for the breast compared to contrast-enhanced CT.

In recent years, cDDR, which is an immediate, inexpensive, and low-radiation diagnostic imaging method, has been expected to be useful in PE diagnosis. cDDR can reduce the exposure dose to about half to 1/20 of that of pulmonary perfusion scintigraphy.

We are currently conducting a proof-of-concept (PoC) phase collaborative study on the diagnostic performance of PE using cDDR. We evaluated the concordance rate between cDDR and clinical diagnosis in patients with PE diagnosed by cDDR. A part of the results is shown here.

1. Case 1: Case with PE ruled out

Fig. 1 shows a case of suspected PE, in which PE was ruled out as a result of cDDR. Pulmonary circulation images by cDDR showed uniform circulation distribution in

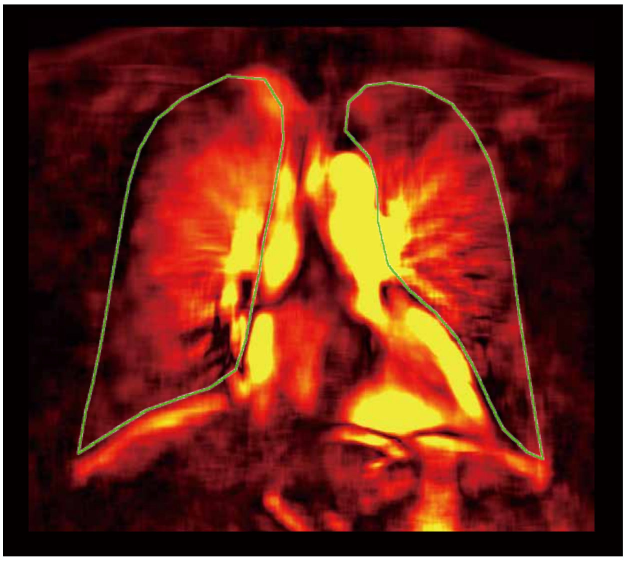


Fig. 1 Case 1: Suspected PE → PE ruled out

the right and left lungs simultaneously (**Fig. 1**).

2. Case 2: PE case

Pulmonary circulation images (**Fig. 2a**) by cDDR in another case diagnosed as PE. Defect areas in the right lung and left lower lung field were observed, and delayed circulation in the right upper lung field was also observerd. Contrast-enhanced CT images showed thrombus occlusion in the upper and lower lobes of the right lung, and thrombus occlusion from the lingual region to the lower lobe of the left lung **(Fig. 2b).** Perfusion scintigraphy was also performed later, and a perfusion defect image similar to the cDDR image was confirmed **(Fig. 2c).**

Fig. 2 Case 2: PE case

3. Case 3: Difficult case

This case was referred to the department of cardiology because the patient complained of dyspnea and elevated D-dimer was confirmed on the 10th day after laparotomy. Although pulmonary circulation imaging by cDDR showed a homogeneous and undelayed circulation distribution (**Fig. 3a**), contrast-enhanced CT showed thrombus occlusion in the anterior basal branch of the right lung and the lingual branch of the left lung, and a diagnosis of peripheral PE was made (**Fig. 3b**). In addition, pulmonary perfusion scintigraphy showed similar perfusion defects in the right lower lung field, but it was difficult to clearly diagnose PE (**Fig. 3c**).

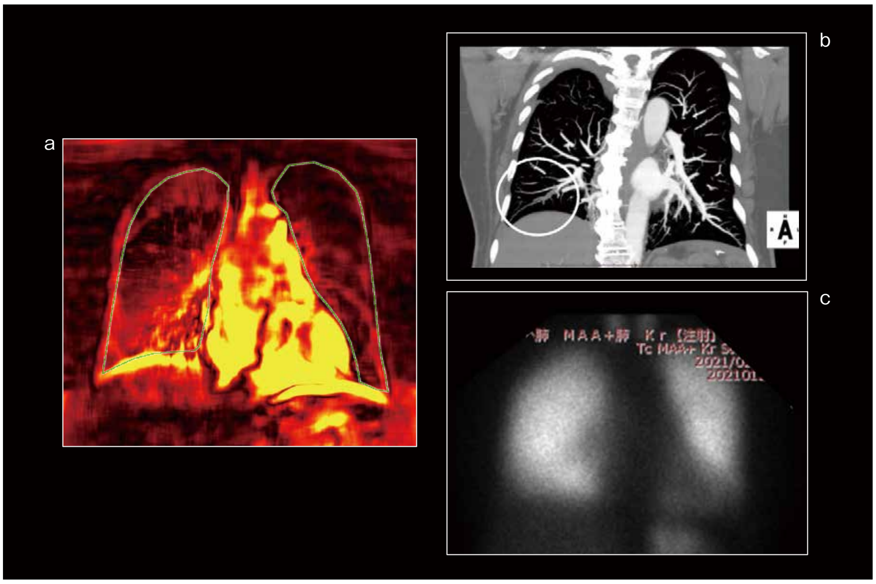


Fig. 3 Case 3: Difficult case

Summary

cDDR in the diagnosis of PE has the advantages; it does not require contrast media, radioisotopes, or intravenous drugs, and the examination time is only a few minutes. In addition, while it can be performed with low radiation exposure, it can be expected to have the same spatial resolution as pulmonary perfution scintigraphy, and may become an alternative modality for the diagnosis of PE characterized as central. In the future, it will be necessary to clarify the positive/negative predictive value and to determine its clinical significance.

●References

1) Barritt, D.W., Jordan, S.C. : *Lancet*, 1: 1309- 1312, 1960.

Evaluation of pulmonary function using chest dynamic x-ray images

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

Pulmonary function test is important to determine the severity of the disease at the time of diagnosis and to monitor therapeutic management because worsening of pulmonary function is directly related to patients' symptoms and prognosis. We will report the evaluation of pulmonary function using chest Dynamic Digital Radiography (cDDR), focusing on the results in our study.

Pulmonary function assessment using cDDR

In chronic obstructive pulmonary disease (COPD), pulmonary function is getting worse due to airflow limitation and hyperinflation. In idiopathic pulmonary fibrosis (IPF), pulmonary function is getting worse due to fibrosis. When cDDR are compared with those of patients with normal pulmonary function, COPD shows increased x-ray translucency of the lung fields and decreased lung motion due to hyperinflation, while IPF shows reticular shadows, ring-shaped shadows, and decreased lung volume, indicating decreased lung motion with respiration.

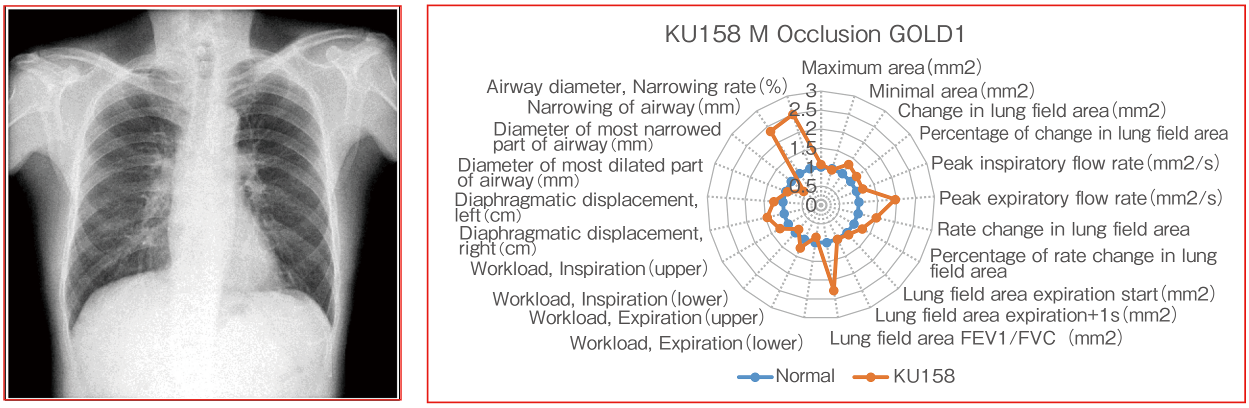
The advantages of cDDR are that it is minimally invasive, simple, and can be evaluated repeatedly; it can be used even when breathing is unstable; and it can visualize pulmonary function and is easily understood by the patient. It is expected to be useful for monitoring and determining the severity of respiratory diseases with decreased pulmonary function.

Usefulness of cDDR for classification of ventilatory defects

We investigated the relationship between parameters (tracheal diameter change, diaphragmc motion, and lung filed area change) obtained from cDDR and ventilatory defect at our institution[1]. In this study, 273 patients with preoperative lung cancer, interstitial lung disease (ILD), COPD, and Asthma who underwent cDDR and pulmonary function tests were included. FEV1.0% < 70% was defined as obstructive ventilatory defect (AL), %FVC < 80% was defined as restrictive ventilatory defect (RD), and patients with none of those were defined as normal. The severity of airflow limitation in AL was classified as mild for %FEV1.0 ≧ 80%, moderate for 50% ≦%FEV1.0 <80%, and severe for %FEV1.0 < 50%. The severity of RD was classified as moderate for %FVC <80% and severe for %FVC <65%. In AL, there was a decrease in the Maximum Mid-Expiratory Flow (MMEF), an increase in residual volume(RV), an increase in RV/TLC(total lung capacity), and a decrease in diffusing capacity as well as a decrease in FEV 1.0. In RD, decreases in RV and diffusing capacity were observed along with decreases in vital capacity.

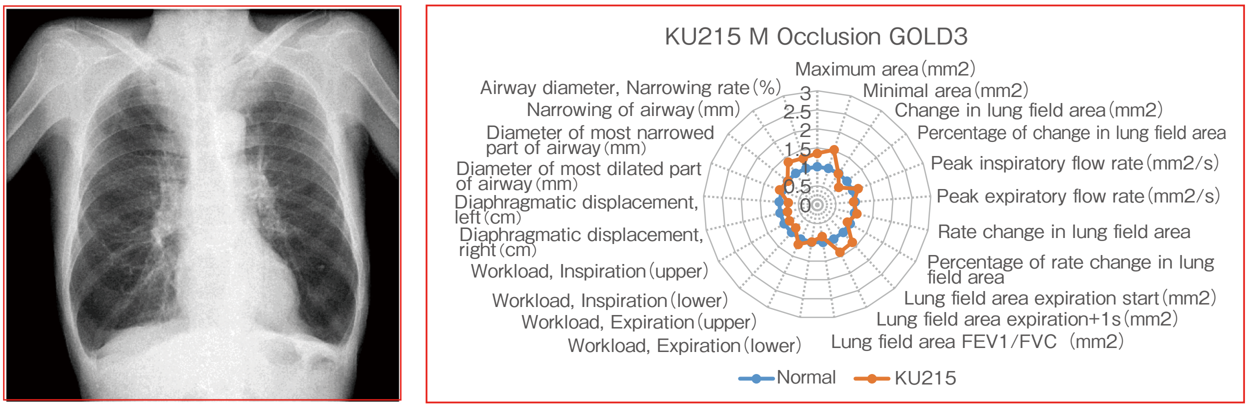
In this study, we observed three parameters: the rate of change in tracheal diameter during maximumin halation and exhalation, the excursion of the left and right diaphragm, and the rate of change in lung field area due to respiratory motion. As a result, lung field area/height at maximum inhalation was significantly increased in the severe AL and significantly decreased in RD compared to the normal group. As a result of each parameter, the rate of change of tracheal diameter increased with severity in AL, while in RD it remained the same as in the normal group, showing a different pattern in AL and RD. The excursion of the right and left diaphragm and the rate of change in lung field area decreased with severity in both AL and RD. It was demonstrated that the visual pattern of cDDR can be used to evaluate pulmonary function.

ROC analysis of various parameters for diagnosis of AL and RD showed that the maximum inhalation lung field area was AUC 0.88 for RD



VC (L)		IRV (L)	ERV (L)	IC (L)	IC/TLC	TV (L)	FVC (L)		FEV1 (L)		FEV1% (G)		MMF .CL/s)		FRC (L)		RV (BTPS) (L)		TLC (L)		RV/TLC	
Measurement	%	Measurement	Measurement	Calculated value	Calculated value	Measurement	Measurement	%	Measurement	%	Measurement	%	Measurement	%	Measurement	%	Measurement	%	Measurement	%	Measurement	%
3.79	120.7	2.57	0.62	3.17	0.50	0.60	3.79	120.7	2.26	103.7	59.6%	94.5	0.65	23.9	3.16	99.4	2.54	131.6	6.33	119.2	40.1%	110.5

Fig. 1 Radar chart of cDDR parameters: mild COPD (GOLD 1)



VC (L)		IRV (L)	ERV (L)	IC (L)	IC/TLC	TV (L)	FVC (L)		FEV1 (L)		FEV1% (G)		MMF .CL/s)		FRC (L)		RV (BTPS) (L)		TLC (L)		RV/TLC	
Measurement	%	Measurement	Measurement	Calculated value	Calculated value	Measurement	Measurement	%	Measurement	%	Measurement	%	Measurement	%	Measurement	%	Measurement	%	Measurement	%	Measurement	%
2.84	89.6	0.45	1.75	1.09	0.18	0.64	2.84	89.6	1.04	46.2	36.6%	58.4	0.40	14.6	5.13	145.7	3.38	169.8	6.22	112.9	54.3%	150.4

Fig. 2 Radar chart of cDDR parameters: severe COPD (GOLD 3)

detection. The rate of change of tracheal diameter may be useful for the detection of AL (and AUC was 0.67). The AUC for detecting moderate disease or more was 0.67 to 0.70, although the excursion of the left and right diaphragm and the rate of change in lung field area decreased with the severity of both AL and RD.

The possibility of assessing pulmonary function using dynamic analysis parameter

In the period of COVID-19 pandemic, pulmonary function tests are difficult to perform for infection control, but we believe that cDDR will be useful as an alternative to pulmonary function tests for screening and monitoring.

Fig. 1 showed the cDDR parameters in mild COPD (GOLD 1) in a radar chart. In this case (orange), the tracheal diameter narrowing rate was higher than that of normal (blue), suggesting pulmonary hyperinflation. In addition, it was said that diaphragmatic excursion was larger than normal in mild COPD, and this could be confirmed in this case. In the radar chart of severe COPD (GOLD 3), tracheal narrowing rate was higher than normal, and the rate of lung filed area change and diaphragmatic excursion were smaller, which is consistent with the data from our institution (**Fig. 2**).

Future prospects

The imaging workstation "KINOSIS" dedicated Dynamic Digital Radiography is now available for clinical use, and more clinical data on the usefulness of respiratory motion analysis will be obtained in the future. The usefulness of cDDR for screening and severity evaluation of respiratory diseases and monitoring of disease progression is expected.

●References
1) Ohkura, N., et al. : *Int. J. Chron. Obstruct. Pulmon. Dis*., 16: 1393-1399, 2021.

Evaluation of Pulmonary Function in Interstitial Lung Disease by Chest Dynamic Digital Radiography

Masakuni Ueyama, MD Department of Respiratory Medicine, Tenri Hospital

Pulmonary function tests are very important in the diagnosis of interstitial pneumonia (IP), and in particular, change in forced vital capacity (FVC) is known to be a marker of disease progression in IP. On the other hand, pulmonary function tests are associated with patient burden due to examination, risk of worsening pneumothorax and mediastinal emphysema, and risk of infection, etc. Therefore, less invasive and more accessible tests are desired. We will report a study on the evaluation of pulmonary function in IP using chest Dynamic Digital Radiography (cDDR) at our hospital.

Evaluation of pulmonary function in IP

1. Objectives, methods, and patient background

We investigated whether it is possible to evaluate pulmonary function in IP by creating a model that can predict FVC and etc based on the correlation between the parameters extracted from cDDR and the conventional pulmonary function test results.

This study was a single-center prospective observational study, and the subjects were 97 IP patients who visited our hospital as outpatients from June 2019 to April 2020. We performed cDDR on the same day as the pulmonary function test and examined the test-retest reliability of the 25 patients who underwent the second imaging. From cDDR, the images at the timing of maximum inhalation and exhalation were extracted, and the lung field area in Post-anterior and Lateral images was measured. In addition, we calculated the estimated lung volume using the previously reported estimation formula. The patients were mainly in their 70s, the male to female ratio was 7:3, and the median of %FVC was 89.2%. The distribution of ventilatory defect pattern was; normal pulmonary function in about 50%, restrictive in about 30%, and obstructive in about 10%.

2. Verification

The correlation coefficient between FVC and the lung field area and at maximum inhalation in the frontal image of cDDR was 0.73, and this correlation coefficient value was improved to 0.86 when the information of the lateral image was added. The similar high correlation was observed between total lung capac-

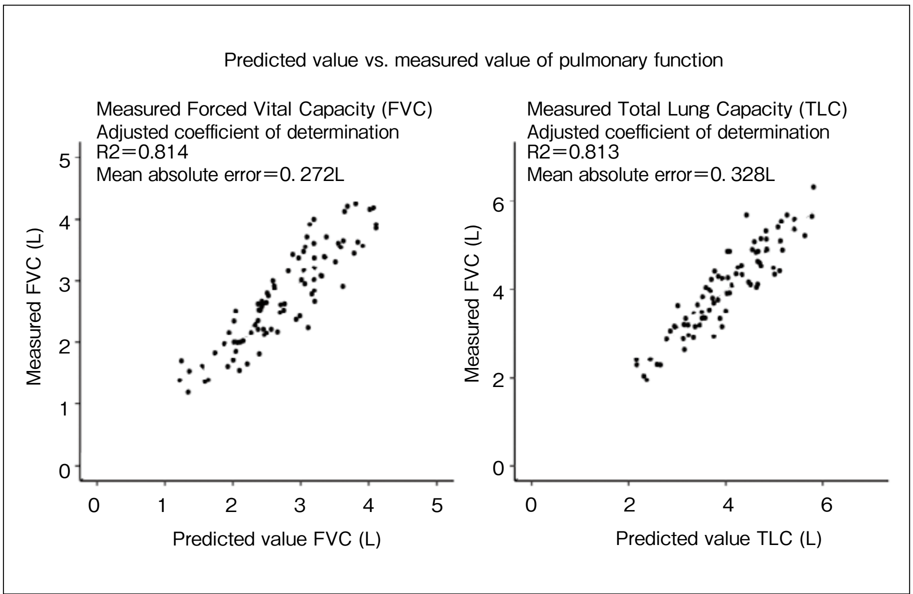


Fig. 1 Predicted value vs. measured value of pulmonary function

ity (TLC), functional residual capacity (FRC), and FEV1.0 as well.

In addition, a prediction model was created by multiple regression analysis using the estimated lung volumes during inhalation and exhalation, age, gender, and BMI as predictor variables. The estimated lung field volume during inhalation and exhalation, age, gender, and BMI were important variables for predictions for FVC; the estimated lung volume during maximum inhalation was important variable for prediction for TLC; the estimated lung volume and BMI during maximum inhalation were important variables for FRC; and the estimated lung volume during maximum inhalation and exhalation and BMI were important variables for residual volume (RV). This may mean that as the volume of the lung itself increases, not only TLC but also FVC, FRC, and RV increase in proportion to it. In addition, the R-Square of the model for FVC and TLC calculated from the predicted values of pulmonary function obtained by the above prediction model and the actual measured values of pulmonary function tests was over 0.8, indicating high predictive ability **(Fig. 1)**.

3. Discussion and future subject

The mean absolute error (MAE) of the FVC model in this study was 270 mL, which is somewhat inaccurate, but we believe that the prediction accuracy can be improved to a clinically applicable level by averaging multiple measurements.

The advantages of cDDR include the ease of obtaining homogeneous images consistently because the images are taken with voice guide, the possibility of simultaneously evaluating the maximum inhalation and exhalation times in a single imaging acquisition, and the possibility of extracting the timing of the maximum inhalation and exhalation while viewing the multiple frame image as cine-loop.

In this study, only patients with mild IP who could undergo pulmonary function tests were included, so whether it can be applied to the elderly and severe cases is a subject for further study. In addition, additional studies are needed to determine the extent to which changes in the disease progression can be detected sensitively.

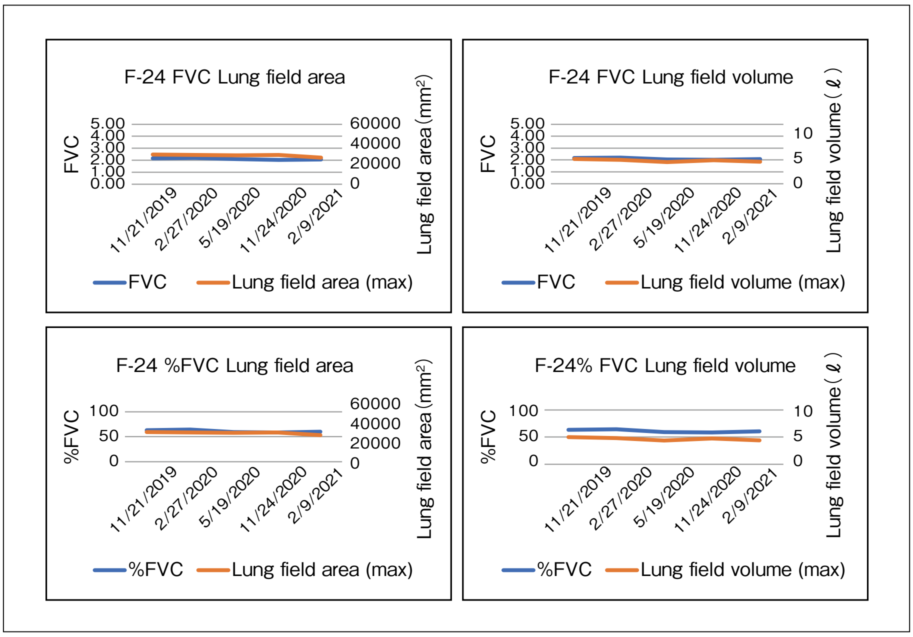


Fig. 2 Comparison of lung field area and lung field volume with FVC

Follow-up case

The patient was a 71 y.o. male with chronic hypersensitivity pneumonitis (CHP), who underwent cDDR 5 times as a follow-up. **Fig. 2** shows the comparison between the lung field area, lung field volume, and FVC, both of which show a similar trend. By using the estimation equation of the multiple regression model described above, we expect that the error will be further reduced.

The condition of this patient was stable and there was little change in FVC. However, it will be interesting to see how cDDR parameters change in the future when the disease progresses.

Summary

The lung field area and estimated lung field volume obtained by cDDR were correlated significantly with the pulmonary function test in IP patients and were useful for predicting pulmonary function test result such as FVC. In addition, cDDR is less invasive and more accessible than pulmonary function test, and is expected to be applied clinically as a new tool that realizes imaging evaluation and pulmonary function evaluation all-in-one.

Exective Remarks

Exective Remarks 1

Yoshikazu Inoue, MD Executive Director, Clinical Research Center, National Hospital Organization Kinki-Chuo Chest Medical Center

The Fleischner Society, of which I was the president at the time, held the Fleischner Society Endorsed Educational Seminar on November 3, 2020. In the morning session of the seminar, we provided an opportunity for domestic and overseas doctors of thoracic imaging to learn about the research results of Dynamic Digital Radiography(DDR). In a questionnaire survey conducted after the session, overseas participants showed a high level of interest in DDR.

In addition, through today's seminar, I recognized that more evidence for DDR was accumulated. Even in thoracic imaging, the concept of functional imaging to evaluate lung function has been accumulated to date. Among them, DDR has many advantages, such as a minimally invasive examination without contrast media and low cost. In addition, in the 20-year history of research, data has been accumulated and many papers have been published. From presentations in this seminar, I strongly felt that it has progressed to the level of insurance coverage and inclusion in the guidelines for each disease.

As for imaging tests for respiratory diseases, CT and Scintigraphy are essential for definitive diagnosis, but various analysis modes of DDR may be useful for screening and follow-up to do repeated examinations. In addition, I feel that DDR is highly useful in severe infections such as COVID-19 and in severe cases where the patient is unable to breathe. The possibility of application is expanding because the motion of bones outside the thorax can be observed.

In addition, for interstitial lung disease (ILD), which is my specialty, the correlation with the pathology has been shown. In the future, it is important to standardize the imaging method to quantify the motion. This problem can be solved by increasing the number of cases, and it is expected to be applied not only to ILD but also to airway lesions, vascular lesions, and pleural lesions. In addition, new findings may be obtained by performing DDR before and after applying exercise stress with an ergometer, etc., for severity assessment and prognosis prediction.

I heard that DDR would be introduced in Europe, U.S., and Asia, and its future development is very exciting. Further accumulation of evidence and technical advances such as the development of new analysis modes, have the potential to revolutionize whole-body diagnostic imaging.

Exective Remarks 2

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

The 3rd Dynamic Digital Radiography(DDR) Seminar was held on the web under COVID-19 pandemic, but more than 800 participants, including physicians, technologists, and industry professionals from Japan and overseas, attended the seminar, reaffirming the high level of interest in DDR technology.

In Part 1, "Technology/Thoracic Surgery," Dr. Daigo Kuroda of Tenri Hospital reported on the problem of reproducibility of respiratory motion in DDR and how to improve it. Dr. Motofumi Ohuchi of Seirei Yokohama Hospital reported on the preoperative evaluation of pleural adhesions in thoracic surgery, and Prof. Haruhiko Kondo of Kyorin University reported on various cases of DDR in thoracic surgery and the possibility of future applications. In Part 2, "Pulmonary Circulation," Dr. Kozo Yamasaki of Kyushu University reported on pulmonary circulation imaging in pulmonary arterial hypertension, and Dr. Kazuya Hosokawa reported on clinical applications in acute pulmonary embolism. In Part 3, "Pulmonary Function," Dr. Noriyuki Ohkura of Kanazawa University reported on the evaluation of pulmonary function in obstructive and restrictive ventilatory defects, and Dr. Masakuni Ueyama of Tenri Hospital reported on the application to pulmonary function evaluation in interstitial lung diseases, focusing on lung field area and estimated lung volume.

All the presentations were excellent, and we could feel the possibility of clinical application in the future as various cases were presented. These presentations were also reported in symposia at conferences, and nearly 30 papers were published in a short period of time after the 2nd seminar. The imaging workstation "KINOSIS" of Konica Minolta has been introduced not only in Japan but also in U.S. and China, indicating the rapid development of research on DDR originated from Japan.

In the opening remarks, Prof. Hiroto Hatabu concluded by saying, "Let us open a new page of the future." In 1895, Roentgen discovered x-rays and invented their clinical application. And in the 1970s, Hounsfield and Cormack developed one of the first computed tomography (CT). Thus, for 125 years, the technology using x-rays has made long strides through several epochs.

DDR is a development to physiological evaluation which looks at not only the motion of the body representing function, but also, in the case of the chest, ventilation and blood flow through temporal changes in x-ray image density. In this sense, it truly opens up a "new page of the future." I would like to work together to make this technology from Japan useful for clinical practice around the world.

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1 Sakura-machi, Hino-shi, Tokyo 191-8511, Japan
Tel: +81 42-589-8145   Fax: +81 42-589-1716