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The 4th Dynamic Digital Radiography Seminar

Date and time : 13:00 to 17:00,
Saturday, June 25, 2022

Venue : Online

CONTENTS

KONICA MINOLTA JAPAN, INC.

Overview

Konica Minolta, Inc. held the 4th Dynamic Digital Radiography Seminar online on Saturday, June 25, 2022. Dynamic Digital Radiology (DDR) developed by Konica Minolta, Inc. is now available to be used in combination with an X-ray equipment for diagnosis "RADspeed Pro" (by Shimadzu Corporation) and with a new portable X-ray imaging system for round visits "AeroDR TX m01" to facilitate the availability of X-ray dynamic imaging in an ICU, a hospital ward, and at a patient's bedside in an operation room.

In this seminar, Mr. Tomohide Sato (Department of Modality, Healthcare Headquarters, Konica Minolta, Inc.) introduced the AeroDR TX m01, following a greeting by Mr. Kazuhiro Kobayashi (Director, Healthcare Headquarters, Konica Minolta, Inc.), and an opening address by Prof. Hiroto Hatabu (Radiology, Harvard Medical School).

The seminar was divided into 3 parts by topic; after each lecture there was a panel discussion led by a chairperson, lecturers, and 3 commentators: Mr. Shoji Kudoh (Representative Director, Japan Anti-Tuberculosis Association), Dr. Haruhiko Kondoh (Department of Thoracic and Thyroid Surgery, Faculty of Medicine, Kyorin University) and Dr. Yasuhiro Gon (Division of Respiratory Medicine, Department of Internal Medicine, Nihon University).

Part 1: Portable Solution (for Intensive Care)

Part 1 chaired by Prof. Terumitsu Hasebe (Department of Radiology,Tokai University School of Medicine) focused on a portable imaging (for intensive care); Dr. Yuri Kon (Department of Emergency and Critical Care Medicine, St. Marianna University School of Medicine) and Mr. Nagaharu Takakura (St. Marianna Medical School Hospital Imaging Center) reported on a case using the AeroDR TX m01 that St. Marianna Medical School adopted in January 2022.

To begin, Dr. Kon gave a lecture entitled "Use of Mobile Dynamic Digital Radiography system in Emergency and Intensive Care Medicine.". She has proposed that an X-ray imaging apparatus may allow complications to be detected via evaluation of pulmonary and cardiac function, and quantification/comparison of the images obtained to clarify the shifting patients' conditions within the ICU. This is made more difficult for patients with multiple organ failure, and renal failure for whom contrast media is contraindicated.

Then, Mr. Takakura talked about his experiences in using AeroDR TX m01, from the standpoint of an X-ray technologist. In his assessment, AeroDR TX m01 is narrow enough to work well for all portable imaging situations, and is very reproducible due to its aliment support function which indicates angles of the FPD and X-ray tube.

Part 2: Pulmonary Function

Part 2 followed on the topic of pulmonary function, with Dr. Atsuko Kurosaki (Department of Diagnostic Radiology, Fukujuji Hospital, Japan Anti-Tuberculosis Association) invited as chairperson.

The session started with a presentation by Prof. Takeshi Isobe (Professor, Department of Internal Medicine, Division of Medical Oncology & Respiratory Medicine, Shimane University Faculty of Medicine) and Mr. Akinori Tsunomori (Healthcare Business Division Development Planning Department, Konica Minolta, Inc.) on a digital case collection project (DDRAtlas) titled "Outline of DDR (Dynamic Digital Radiography) Atlas and How to

Use". DDRAtlas comprehensively aggregates information on normal motions in order to establish and study the diagnostic standards for X-ray dynamic images, and initiate education. At the moment, as a case collection for the respiratory field, "DDRAtlas Ver. 1.0" is available on the dynamic digital radiography membership website. Dr. Isobe, one of the DDRAtlas editors, introduced how to use its contents, and asked for support in collecting relevant cases. Furthermore, Mr. Tsunomori was determined to support X-ray dynamic imaging to spread by providing advanced diagnostic technology in use of the platform and analytical methods for large volume data analysis, and Artificial Intelligence (AI) applications.

Finally, Dr. Kentaro Hayashi (Department of Internal Medicine, Division of Respiratory Medicine, Nihon University School of Medicine) presented on "Assessment of Emphysema by Dynamic Digital Radiography". He is observing a correlation between low attenuation area (LAA) scores in CT images and signal decreasing field in X-ray images, with the hope of applying X-ray dynamic analysis to chronic obstructive pulmonary disease (COPD) screening tests.

Part 3: Clinical Practice

Prof. Kei Takase (Diagnostic Radiology, Tohoku University School of Medicine) chaired Part 3, which included three lectures on current clinical practice.

Dr. Yuzo Yamasaki (Department of Clinical Radiology, Graduate School of Medical Sciences, Kyushu University) gave a presentation entitled "Clinical Application of Dynamic Analysis in Pulmonary Circulation Assessment-focusing on pulmonary embolism". He emphasized that dynamic imaging is usable, available, and could be an option for follow-up of high-risk patients with chronic thromboembolic pulmonary hypertension (CTEPH) post-acute pulmonary embolism when their condition precludes contrast-enhanced CT.

Then, Dr. Kazushi Kitamura (Department of Radiology, Tenri Hospital), talked about "Application of Dynamic Digital Radiography (DDR) imaging to Radiotherapy". He described his team's efforts in quantitative measurement of tumor migration in combination with dynamic analysis software for accurate evaluation of respiratory movement of pulmonary masses in Stereotactic Body Radio Therapy (SBRT) He noted that dynamic X-ray imaging is advantageous in terms of cost, quality of imaging, and workflow.

For the final lecture in Part 3, Dr. Naoya Hashimoto (Department of Radiology, Kyorin University Hospital) made a presentation on "Collaboration with Clinical Departments and Imaging Techniques - as a standard examination". He reported cases of enlargement and positioning of applicable indications, a utilization of Auto Voice, and a study of low radiation doses.

Exective Remarks

To conclude, Dr. Kondoh and Dr. Kudoh made general comments, outlining their expectations for the further development and progression of dynamic X-ray imaging.

Opening Remarks

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

X-ray dynamic imaging (Dynamic Digital Radiography: DDR) technology is based on the research developed and published by Prof. Shigeru Sanada, Prof. Rie Tanaka, et.al. of Kanazawa University early in 2000's. Konica Minolta has developed this technology for the last 20 years. Dr. Shoji Kudoh, Representative Director of Japan Anti-Tuberculosis Association, a leading expert in the respiratory internal medicine and physiology in the world, paid attention to the technology previously, and has imaged about 600 cases in Fukujuji Hospital since 2009.

Life is interwoven with meetings and chances. When Governor Yuji Kurokawa of Kanagawa Prefecture and others visited Harvard University in 2014, he had an opportunity to get to know the person responsible for DDR at Konica Minolta. I also came to participate in the research of DDR. Two years later, Dr. Rie Tanaka, and Dr. Yoshitake Yamada of Keio University, who was studying at Harvard Medical School at that time, received an award for this research study at the 102nd Radiological Society of North America (RSNA 2016), resulting in the technology drawing attention from all over the world.

Let me introduce recent research results of X-ray dynamic imaging. In 2020, Dr. Takuya Hino of Kyushu University reported in his thesis entitled "Projected lung areas using dynamic X-ray (DXR)" (*European Journal of Radiology Open*) that information similar to pulmonary function tests may be obtained by monitoring X-ray attenuation and lung field areas over time. Prof. Akinori Hata of Osaka University published "Dynamic Chest X-Ray Using a Flat-Panel Detector System: Technique and Applications" (*Korean Journal of Radiology*) in 2021. This paper is a review of X-ray dynamic imaging based on the presentation by Dr. Yoshitake Yamada at the RSNA 2016 meeting. Dr. Takuya Hino has been working on the analysis of pulmonary function, and has published his study as "Vector-Field Dynamic X-ray (VF-DXR) using Optical Flow Method" (*The British Journal of Radiology*) in 2022. He also applied VF-DXR to chronic obstructive pulmonary disease (COPD) in his study "Vector-field dynamic X-ray (VF-DXR) using the optical flow method in patients with chronic obstructive pulmonary disease" (*European Radiology Experimental*), and pointed out a correlation with its severity.

As shown above, Dynamic Digital Radiography technology is originally from Japan, and has been developed by tremendous efforts of many researchers. I am convinced that shortly this technology will be more available to the people of the world. Over 100 units of DDR have already sold in the world, and many medical institutions are scheduled to soon install DDR. Taking this opportunity, I would like to ask you to further understand this technology with your efforts to turn a "new future page".

The 4th Dynamic Digital Radiography Seminar

Date and Time : June 25, 2022 (Saturday) 13 : 00-17 : 00

Venue: Online

Chairperson:

Part 1 : Terumitsu Hasebe, MD, PhD (Department of Radiology,Tokai University School of Medicine)

Part 2 : Atsuko Kurosaki, MD, PhD (Department of Diagnostic Radiology, Fukujuji Hospital, Japan Anti-Tuberculosis Association)

Part 3 : Kei Takase, MD, PhD (Diagnostic Radiology, Tohoku University School of Medicine)

Commentator:

Shoji Kudoh, MD, PhD (Representative Director, Japan Anti-Tuberculosis Association)

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

Yasuhiro Gon, MD. PhD (Division of Respiratory Medicine, Department of Internal Medicine, Nihon University)

After each part was over, a panel discussion took place having the chairperson of the part, lecturers and 3 commentators.

Use of a Mobile Dynamic Digital Radiography system in Emergency and Intensive Care Medicine.

Yuri Kon, MD Department of Emergency and Critical Care Medicine, St. Marianna University School of Medicine

The Dynamic Digital Radiography (DDR) application is already available with a stationary X-ray system, to evaluate pulmonary function, predict post-operative pulmonary function, and detect adhesion/invasion, as well as evaluate pulmonary circulation and cardiac function. Our hospital introduced a mobile X-ray system that can acquire DDR, named "AeroDR TX m01"(Konica Minolta) in January 2022, which made DDR possible in an intensive care unit (ICU). In this report, I will share my experiences in DDR imaging in the ICU.

Expectations for Dynamic Digital Radiography in ICU

In ICU, patients with serious multiple organ failures, like septicemia, acute respiratory distress syndrome (ARDS), pneumonia, cardiac insufficiency, myocardial infarction, and cerebral hemorrhage, are being treated. Patients are usually connected to ventilators, dialysis catheters, extracorporeal membrane oxygenation (ECMO), various monitors, and drainage tubes for treatment. Therefore, imaging diagnosis routinely done in an ICU are limited to those that can be done without moving the patient, such as portable X-ray and ultrasound; the location of devices and gross lesions can only be confirmed.

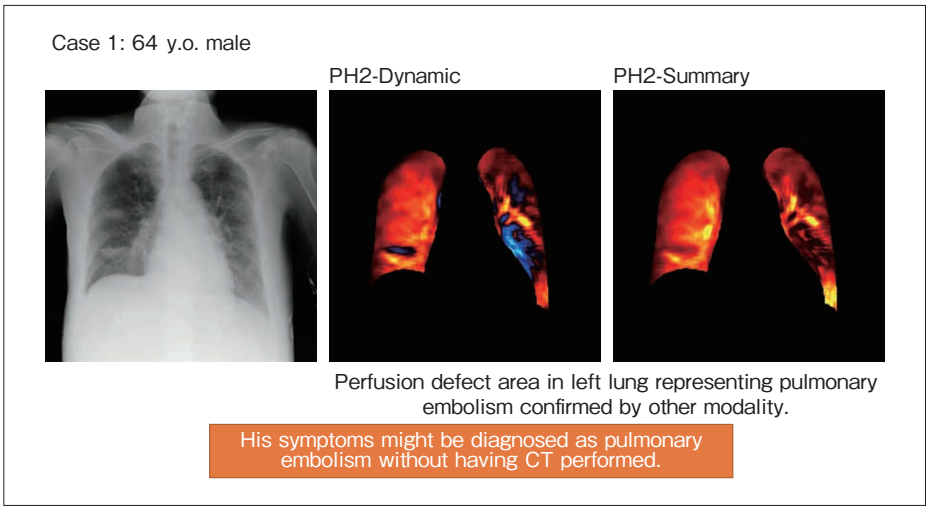

Fig. 1 Case 1: with pulmonary embolism

ICU patients are seriously ill and often have major complications, such as ventilator-associated pneumonia and pulmonary embolism. For instance, in the case of septic shock, which could lead to shock and hypoxia during high-flow catecholamine administration under ventilator management. In these cases, CT scanning is recommended to diagnose any causative conditions; however, high risks are associated with moving patients for imaging, in addition, the patient might also suffer from multiple organ failures such as renal failure, so that there are concerns in using contrast agents.

Since a mobile DDR system can evaluate pulmonary function, pulmonary circulation function, cardiac function, confirmation of small changes may be possible by incorporating DDR into routine imaging. Depending on the patient's condition, DDR is expected to improve patietn's management.

Case Presentation

In our emergency medical care center, a total of 11 patients have undergone imaging 22 times in the 4 months since AeroDR TX m01 was introduced in January 2022. Of them, let me present two cases:

Case 1: Pulmonary Embolism (64 y. o. male)

The patient was admitted for having sepsis and acute renal failure due to diabetic foot gangrene and diabetic ketoacidosis. His respiratory conditions deteriorated on Day 7, and he underwent plain CT, which then revealed a rise in ground glass concentrations in peripheral branch of the left lung field in the segmental, and pulmonary infarction was suspected. Contrast-enhanced CT imaging would normally be done, but the use of the contrast agent was thought to be highly risky because he suffered from acute renal insufficiency. Thus, DDR was carried out. As a result of analysis by PH2-MODE (PH2-Dynamic, PH2-Summary), blood flow decreased in the entire left lung field, whose results were consistent with the findings from pulmonary infarction. The patient was diagnosed with pulmonary embolism **(Fig. 1).**

Case 2: COVID -19 (63 y. o. male)

The patient was diagnosed with novel coronavirus infection (COVID-19), and underwent intubation for severe hypoxemia that had already been observed at the time of emergency transportation. His respiratory conditions deteriorated afterwards, partial pressure of arterial oxygen (PaO_2)/fraction of inspiratory oxygen (FiO_2) (P/F ratio) lowered to 130, and partial pressure of arterial carbon dioxide (pCO_2) in blood rose to 50 on Day 4, while the static lung compliance (Cstat) showing the swelling of the lung was maintained. Lungs with ARDS confirmed by CT revealed that the normal lung and the impaired lung coexist, and that shadows were strongly depicted in the dorsal lungs, regions under gravity load. Treatment of ARDS may include mechanical ventilation, muscle relaxants, and prone positioning to improve the balance between the normal and impaired lungs and to correct the unbalance in ventilation blood flows. In this case, treatment with prone positioning was tried and the DDR imag was compared with static image before and after the treatment.

In interpreting the static images, infiltrative shadows were depicted densely in the left lower lung field even after the treatment at prone position, suspicious of deterioration of the disease state **(Fig. 2).** However, in analyzing DDR images via PL-MODE, it was indicated that ventilation had improved after the treatment at prone position **(Fig. 3)**. The P/F ratio and pCO_2 improved after the treatment at prone position as shown in results of the blood tests, indicating results from the dynamic images agreed with the actual clinical status.

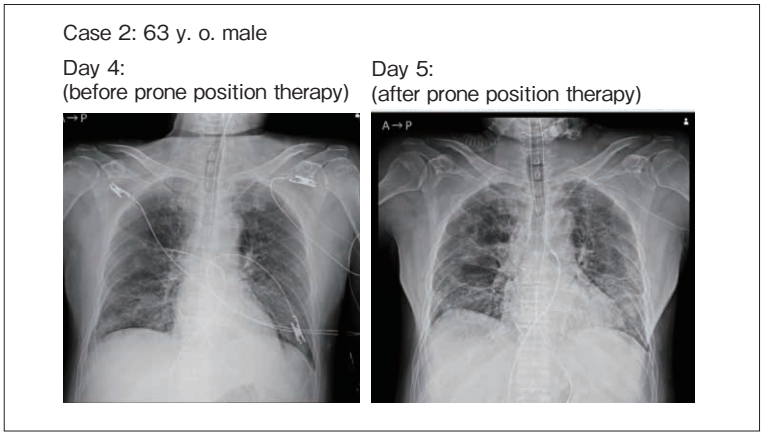

Fig. 2 Case 2 : COVID-19 (static image)

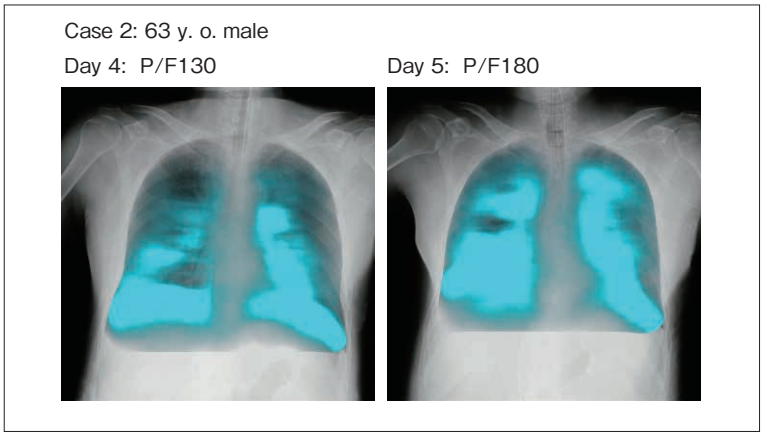

Fig. 3 Case 2 : COVID-19 (DDR image)

Summary

DDR may indicate critical complications in a patient in an ICU, such as pulmonary embolism, without leading to risks related to contrast media and moving of the patient. Ventilation conditions, which are not visualized with static imaging, could be confirmed. If this system can be incorporated in routine examinations and combined with analytical results, ICU patient management will dramatically change.

Experiences in using mobile Dynamic Digital Ragiography system "AeroDR TX m01"

Nagaharu Takakura St. Marianna Medical School Hospital Imaging Center

Our Intensive Care Unit (ICU) and High Care Unit (HCU) (30 beds in total) perform portable imaging 15 times a day on average. In this lecture, I will report our experiences in mobile Dynamic Digital Ragiography(DDR) system, "AeroDR TX m01" (Konica Minolta), in the critical care ward of an Emergency Center.

Workflow for mobile DDR system

A mobile DDR system refers to a imaging to image a functional dynamic state by X-ray pulsed irradiation. It is available even at a patient's bedside and for a patient undergoing mechanical mechanical ventilation. The workflow of DDR imagingcan differ from conventional static radiography in order confirmation, equipment set up, positioning, acquisition, output from the host, and analysis using "KINOSIS" **(Fig. 1).**

In order to grasp the order in detail, a patient's conditions, such as ME equipment mounting (yes/no), breath holding (yes/no), and ventilator mounting (yes/no), are to be confirmed in addition to the purpose of imaging. The optimum protocol will be discussed with the requesting doctor.

We do not do imaging at sitting position in our hospital due to reproducibility. For DDR imaging, an X-ray region is directly provided on both shoulders. An irradiation field is recommended to be expanded to the surface of a detector receiving light at the same level; however, the DDR imaging is basically as practical as the static imaging is.

In DDR imaging, it takes about 25 seconds after starting of the examination, and a wait of about 50 seconds from the end of the first acquisition to the start of the second acquisition in the case of multiple DDR imaging (for example a breath-hold and free respiration exam pair). This does not create large problems in the workflow because such waiting times can be allocated for the

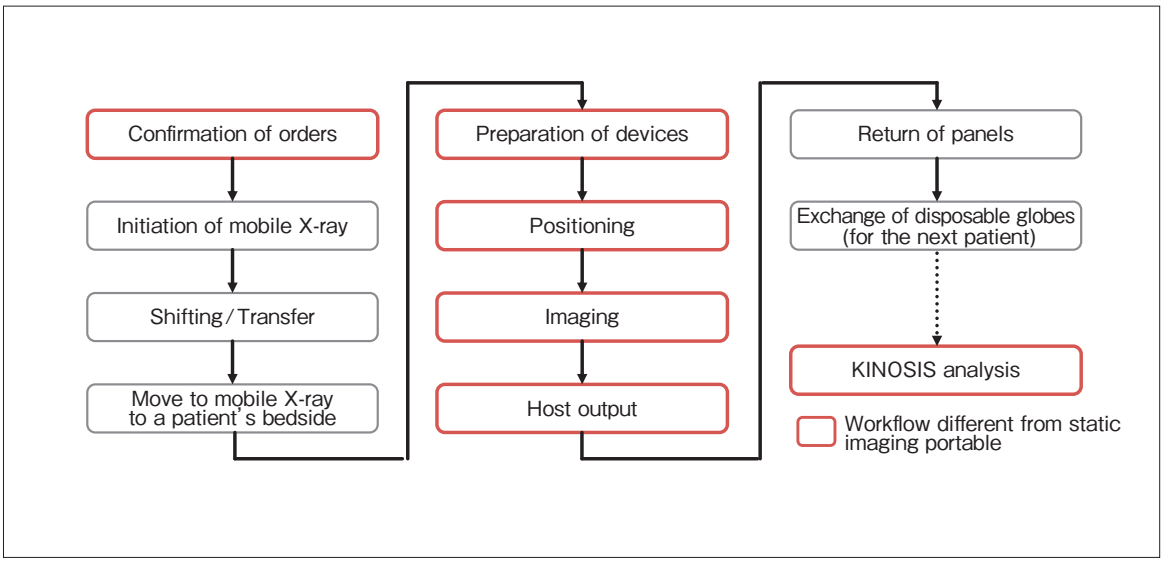

Fig. 1 Workflow for mobile dynamic imaging

◆Collimator with auto filter
Three types of filters (electric) are incorporated for DDR.

Additional filters
None
2mm-Al
1mm-Al 0.1mmCu
1mm-Al 0.2mmCu

Filters can be automatically selected and used according to the key for imaging conditions, and this does not affect the imaging workflow, we are going to assess whether it can be applied to static image.

Fig. 2 Additional filters for selection

preparation, e.g., adjusting a patient's respiration and explaining the imaging to him/her. Even if there is any deficiency found in positioning, it can immediately be handled because the first view is displayed in 2 to 3 seconds after the acquisition starts.

The host output from the mobile DDR system to KINOSIS can be done through the same workflow to that of static image. (IEEE 802.11g is available in our hospital). However, depending on the wireless environment, a wired LAN cable may be used; IEEE 802.11g is available in our hospital so this is not needed. DDR takes longer per exam than for static imaging if KINOSIS analysis is included, but dynamic imaging facilitates improved diagnosis compared to static imaging.

Operability and Usability of AeroDR TX m01

Our hospital is scheduled to be renovated in January 2023, where the critical care ward will be enlarged to accommodate a total of 67 beds with a corridor of about 100 meters long. AeroDR TX m01 has good mobility, and can be used comfortably even in the new critical care ward even though the mobile X-ray system will need to travel longer distances. The battery capacity must be confirmed to be sufficient for multiple DDR exams, because DDR imaging will consume more power than a static acquisition.

AeroDR TX m01 looks larger, at a glance, than the other maker's apparatus being used in our hospital for round visits, but it is so compact to be the narrowest. The main monitor operating the control software "CS -7" is large, being 19 inches in size, with high visibility, so that an operator/engineer may smoothly proceed to the next technique.

The followings are the comments from X-ray technologist:

- AeroDR TX m01 has an operability that can change tube angles. This means it is useful for the medical institutions which perform a lot of DDR imaging in a sitting position.
- The handle sensor was initially difficult to react, which then was resolved by enhancing the sensitivity setting of the sensor.
- Reproducibility can be ensured with the angle displayed between FPD and the X-ray tube.
- Technologists will get used to inserting an X-ray tube to the parking position even though it may be a bit hard at the beginning.
- It would be desirable if the imaging parameters could also be confirmed in the main monitor to enable just one person to operate.

AeroDR TX m01 has 3 additional filters built in for DDR imaging **(Fig. 2)**. Those filters can be automatically selected and used in response to the condition keys for imaging, which therefore does not affect the imaging workflow. AeroDR TX m01 is available for dynamic imaging at the present. Application to static imaging will also be under discussion.

In the future, users and manufacturers are expected to closely collaborate in solving any problems to occur.

Outline of DDR (Dynamic Digital Radiography) Atlas and How to Use

Takeshi Isobe, MD, PhD Professor, Department of Internal Medicine, Division of Medical Oncology & Respiratory Medicine, Shimane University Faculty of Medicine
Akinori Tsunomori Healthcare Business Division Development Planning Department, Konica Minolta, Inc.

Konica Minolta has quantified the motion of X-ray dynamic imaging to establish normal models for digital case collection "DDR (Dynamic Digital Radiography) Atlas". As the first step, "DDRAtlas Ver. 1.0", indicated for respiratory organ regions, was open to the public. The outline, application method, and future prospect are presented.

Background of DDRAtlas Study

Chest X-ray, which is a static image at the maximum inspiration, are used to detect, localize, and characterize lesions and pathology. It is necessary to fully understand the normal image feature of the heart, blood vessel, diaphragm, and other organs on chest X-ray in order to diagnose diseases or conditions.

In the chest X-ray, differentiating normal vs. abnormal images, depends on anatomical or pathological differences that are well-known and an interpretation standard already exists. Addition of the new modality of Dynamic Digital Radiography (DDR) enables us to observe sequential display of X-ray images and to evaluate organ motion, which provides functional information. DDR brings a large paradigm shift in the field of X-ray imaging. For thoracic applications, by quantification of the vertical movement of the diaphragm and changes in the lung size, it is expected to aid in early diagnoses of chronic obstructive pulmonary disease (COPD), which is hyperinflation of the lung and interstitial lung disease, which is reduction of lung volume, evaluation of the effects of therapy, and comparison with pulmonary function tests. In addition, observation of motion may make visual recognition of nodule shadows easier in lung cancer screening.

About DDRAtlas

Konica Minolta has been establishing a normal model (DDRAtlas), which is a database of DDR images with quantified organ motion. The purpose being improvement of diagnostic accuracy through activation of research and education for DDR imaging and establishment of diagnostic criteria. Shimane University is collecting DDR image of normal cases, andperforming clinical research to develop and evaluate the

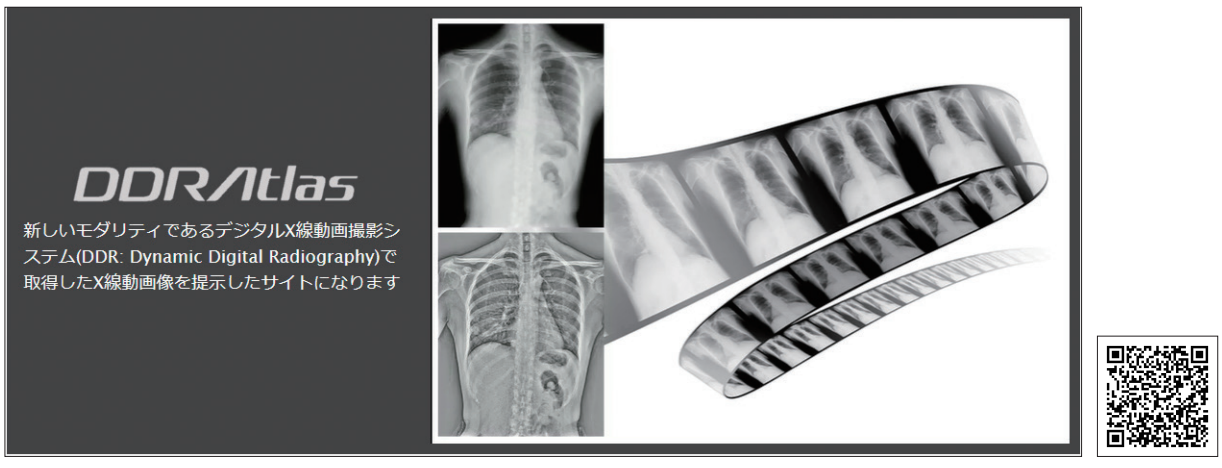

Fig. 1 The front page of DDRAtlas Ver. 1.0

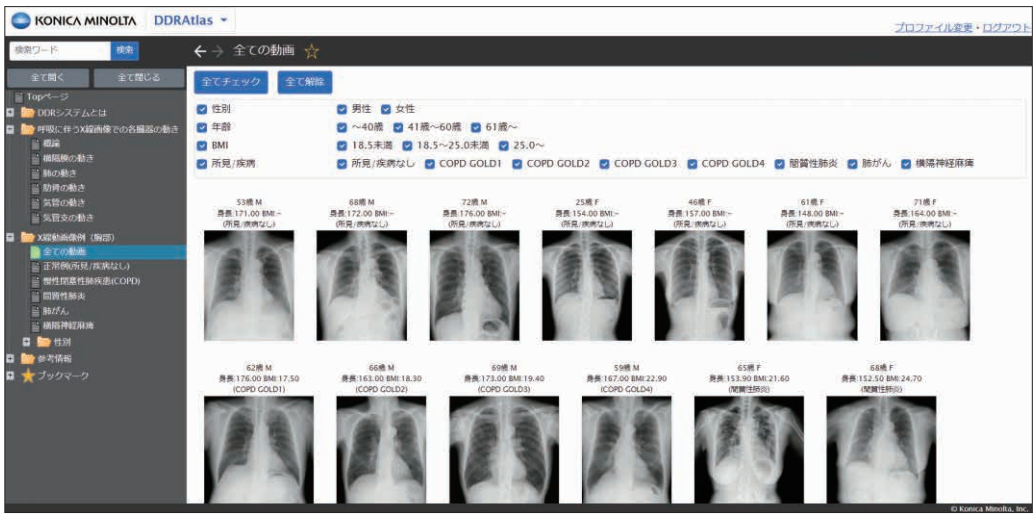

Fig. 2 An example of DDR image (chest)

testing technology for low invasion and dynamic respiratory function.

The concept of DDRAtlas is to have X-ray technologist understand the purpose of the examination when ordered, to clarify an optimum examination technique, as well as to collect information on the interpretation and diagnostic criteria of the images at the time of actual diagnoses and treatments, and to allow for a concrete explanation about the information obtained from DDR images of a patient. Moreover, raising many research questions is expected to contribute to a further investigation of DDR imaging.

DDRAtlas Ver.1.0

As the first DDRAtlas, DDRAtlas Ver. 1.0, targeting the respiratory region, was released on the membership website of the dynamic digital radiography in June 2022 (**Fig. 1**).

DDRAtlas Ver. 1.0 includes an outline of the dynamic digital radiography, movement of each organ during respiration, and cases of DDR images (chest), together with reference information. In the movements of each organ during respiration, computer graphics and anatomical schema of the diaphragm, the ribs, the trachea, the bronchus, and actual DDR images are reported. Taking the diaphragm as an example, its anatomical information, DDR images of normal cases, and measurement examples of excursion are shown in graphs and numerical values. DDR images of a disease case, disease information and smoking history, CT images, etc. are also reported. In addition, results from respiratory function tests, such as forced vital capacity (FVC), forced expiratory volume in 1 second (FEV1), flow-volume curves and actual movement of the diaphragm are visualized, and graphed in data for confirmation.

In a case of DDR images, it is possible to reference normal cases and disease cases such as COPD, interstitial pneumonia, lung cancer, and phrenic nerve paralysis by sex, age, and BMI (**Fig. 2**). Titles and names of the publication journals and the authors of the papers on DDR images are summarized as reference information. There are already about 40 peer-reviewed papers on DDR, which serve as a reference in the context of research questions.

This site can be accessed not only by the medical institutions that have already introduced DDR but also by those considering introduction of DDR.

Future Outlook

Using DDRAtlas, I am considering making the information of the observable motion in DDR available to diagnostic imaging as a routine testing. For the further evolution of DDRAtlas, we would like to invite cooperation from more medical institutions and departments of diagnosis and treatment so that we can collect normal and abnormal cases, and look for/reinforce positive evidence for DDR. Making the contents of DDRAtlas available is part of Konica Minolta's ongoing effort to increase the adoption and availability of DDR. In addition, will to provide platforms and analytical techniques for large data analysis, and advanced diagnostic technology using Artificial Intelligence (AI).

Assessment of Emphysema by Dynamic Digital Radiography

Kentaro Hayashi, MD, PhD Department of Internal Medicine, Division of Respiratory Medicine, Nihon University School of Medicine

Our hospital introduced a dynamic digital radiography (DDR) in October 2021. Patients with chronic obstructive pulmonary disease (COPD), interstitial pneumonia, coronavirus disease-2019 (COVID-19), and preoperative cases with lung cancer are mainly imaged in the Department of Respiratory Organ Medicine and Department of Respiratory Organ Surgery. Until now, DDR has been carried out in over 300 cases, out of which about 130 cases are of COVID-19.

Assessment of Emphysema by DDR

DDR facilitates tracking the movement of the diaphragm and visualizing how much it has moved using the DM-MODE analysis application, visualizing the magnitude of the movement (longitudinal direction) in the lung during expiration by LM-MODE, and visualizing signal changes (evaluation of blood flow over the cardiac cycle) in the lung field by PH2-MODE. Having these analytical images, it is thought to be possible to evaluate limitation of motion by hyperinflation and decrease in blood flow by emphysema in the COPD cases, and the limitation of motion and decreased blood flow by pneumonia in the cases with COVID-19.

Our hospital assessed a relationship between Godard score (pulmonary emphysema evaluation by CT) and PH2-MODE in the area ratio of low signal regions and found that there is a constant correlation between them, regardless of the severity of COPD. Now we are considering assessing emphysema using DDR.

Case 1 is a 73 y.o. male patient with COPD (Stage 2 by GOLD classification; Grade 1 by mMRC; A by New GOLD classification), who showed flatness lowering and hyperinflation of the diaphragm in the chest X-ray. According to the analysis by DM-MODE **(Fig. 1b)**,

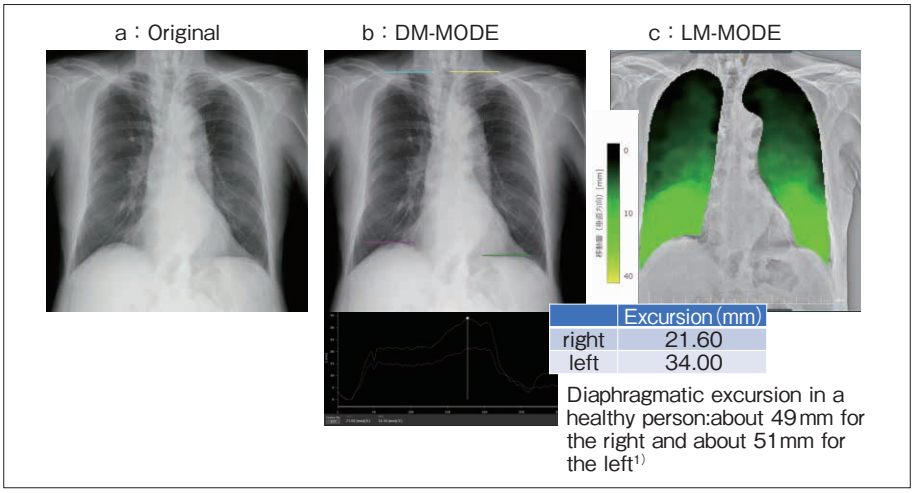

Fig. 1 Case 1: DDR in a COPD case

Fig. 2 PH 2-MODE in Case 1

the diaphragmatic excursion was 21.6 mm for the right and 34 mm for the left (compared to about 49 mm for the right and about 51 mm[1)] for the left in a healthy persons), indicating the range of motion to be limited. LM-MODE **(Fig. 1c)** showed the movement of the lower lung had been limited. In addition, PH2-MODE **(Fig. 2)** pointed out that the presence of emphysema, not detectable by chest X-ray, can be visualized to some extent.

COPD cases show a lowering in excursion of the diaphragm and lung parenchyma. In our study, it is suggested that the LAA (low attenuation area) score of CT images and the signal lowering area by PH2-MODE are related, thus it may be possible to carry out a screening test for COPD using DDR.

Experiences in performing DDR imaging of COVID-19 Case

Let me introduce our experiences in performing DDR imaging of COVID-19 cases in our hospital. Case 2 is a 52 y. o. female, twice vaccinated, who was admitted 7 days after she developed COVID-19. At the admission, the spread of pneumonia was confirmed mainly on both lower lobe sides with chest X-ray and CT. CT images were compared with those on Day 1, Day 8, and Day 45 of hospitalization over time; typical macular symptoms of ground glass shadows and band-like opacity were noted in a certain part on Day 1, but pneumonia had fairly resolved on Day 8 with the intervention provided, and the pneumonia almost disappeared on Day 45, being almost normal.

Her conditions were monitored also with DDR imaging over time. In the DM-MODE **(Fig. 3)**, diaphragmatic excursion was significantly limited to 14.8 mm for the right and 21.6 mm for the left on Day 1, followed by 16.4 mm for the right and 27.6 mm for the left on Day 8, and 35.6 mm for the right and 44 mm for the left on Day 45; this means the conditions were improved, but that excursion was still limited. Lung movement was severely restricted and excursion was very low on Day 1 **(the upper part of Fig. 4)**, but improved on Day 8 following administration of the study intervention. In the PH2-MODE (PH2-Summary) **(the lower part of Fig. 4)**, a lesion was observed corresponding to the pneumonia site in the signal value of PH2-MODE on Day 1, but improved over time.

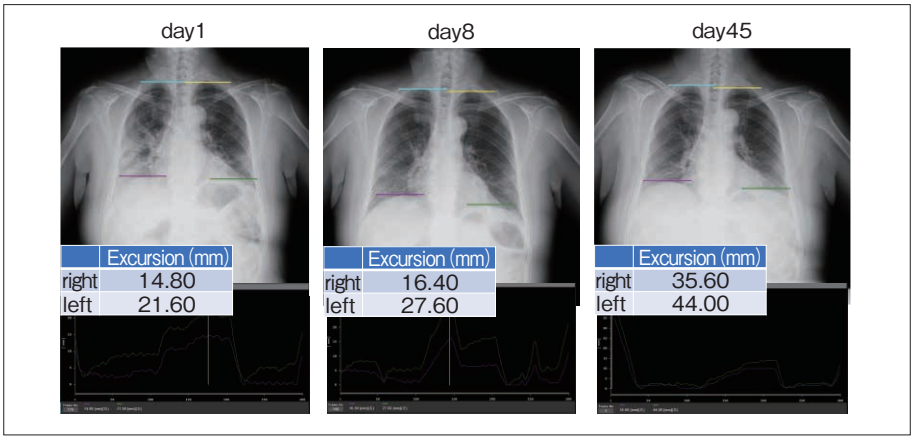

Fig. 3 Case 2: A COVID-19 Case by DM-MODE

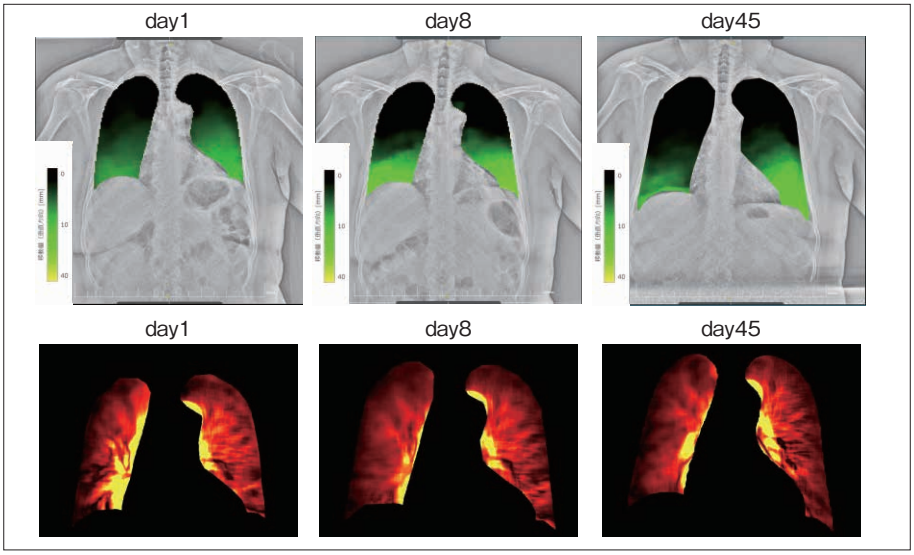

Fig. 4 LM-MODE(the upper part), and PH2-MODE(PH2-Summary) (the lower part) in Case 2

In the pneumonia case with COVID-19, DM-MODE and LM-MODE for DDR pointed out the lowered range of motion. It was proven that this change is also recognized in the early stage with comparatively mild pneumonia complication. There are still many unknowns about the pathology and etiology of COVID-19, to which DDR can contribute to analysis.

●References

1) Hida, T., et al. : *Eur. J. Radiol.*, 113, 59-65,2019.

Clinical Application of Dynamic Analysis in Pulmonary Circulation Assessment
- focusing on pulmonary embolism

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

In this lecture, I report on the clinical application of Dynamic Digital Radiography (DDR) for assessment of pulmonary embolism.

What Does Pulmonary Embolism Look Like on DDR ?

Fig. 1 shows images of various examinations in patients with pulmonary embolism. Contrast-enhanced CT reveals extensive thrombi in the bilateral pulmonary arteries. It is possible to confirm the state in which the blood flow is lowered in the peripheral side by thrombi in bilateral pulmonary arteries also in DDR. The DDR image is very similar to the iodine map and lung perfusion scintigraphy. The defect area shows as a triangle with the periphery of the lung field on the base as done in the other imaging modalities, and can be confirmed as a wedge-shaped defect area with clear defect[1].

In this case, the different analytical method of DDR, PH2-MODE and PH1-MODE, from which similar findings of pulmonary embolism are confirmed (**Fig. 2**). In PL-MODE, which shows changes of image density in the lung field with respiration, no obvious abnormality was confirmed in ventilation, and it appeared as a ventilation-perfusion mismatch.

What does a small pulmonary embolism look like? **Fig. 3** shows a case of a 71 y. o. female with acute pulmonary embolism found incidentally before undergoing the surgery for the liver. Contrast-enhanced CT shows a small thrombus in the right lower lobe; iodine maps show areas

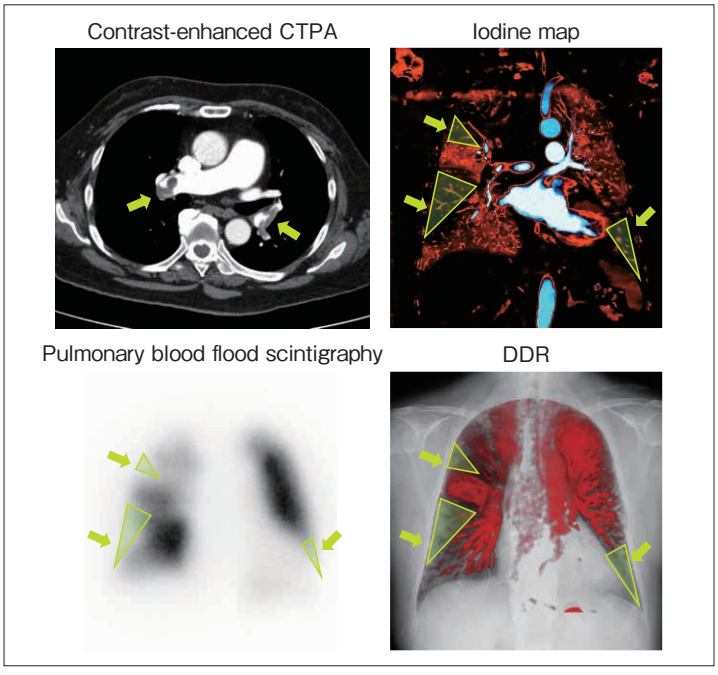

Fig. 1 Various examination images in a patient with pulmonary embolism

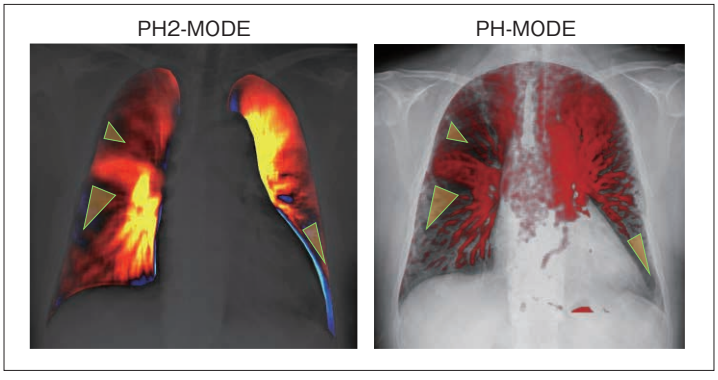

Fig. 2 PH2-MODE and PH1-MODE in the case in Fig. 1

of decreased blood flow in the relevant areas. However, DDR cannot conclusively point out the lowering in blood flow in the same areas, or even in lung ventilation or perfusion scintigraphy. As for a small pulmonary embolism, it can be said that a small thrombus is difficult to detect even with DDR if it is not recognized by a planar V/Q scintigraphy scan (front face).

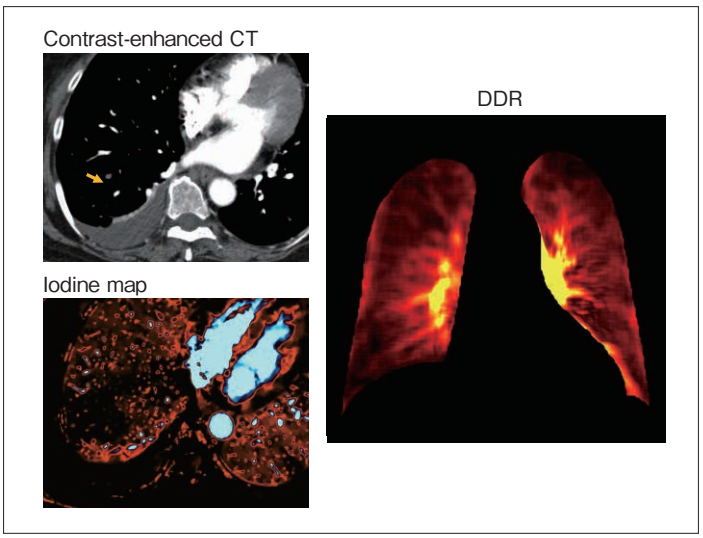

Fig. 3 Detection of small pulmonary embolism

How to utilize DDR for Pulmonary Embolism

DDR is useful to diagnosing pulmonary embolism, but not for detecting a small thrombus; therefore, it may not be preferred when a contrast-enhanced CT is available. Then, is there no chance in performing DDR for a patient who underwent a contrast-enhanced CT for his/her acute pulmonary embolism?

Let me present a case of a 32 y. o. female who was admitted to our hospital by ambulance for cardiopulmonary arrest. Contrast-enhanced CT pointed out bilateral multiple thrombosis. Chest radiography after recovery showed multiple wedge-like defects in both lung fields. After discharge, she continued to undergo oral anticoagulant therapy. Since shortness of breath after exertion remained even after 6 months, DDR was performed **(Fig. 4)**. DDR showed large blood flow defects remaining to some extent in the right upper lung field and the left middle lung lobe. Ventilation-perfusion scintigraphy also showed residual ventilation/perfusion mismatch in the right upper and the left middle lung lobe, suggesting chronic thrombosis. She was readmitted to our hospital and underwent right heart catheterization. She was diagnosed as having chronic thromboembolic pulmonary hypertension (CTEPH) with a mean pulmonary arterial pressure of 26 mmHg.

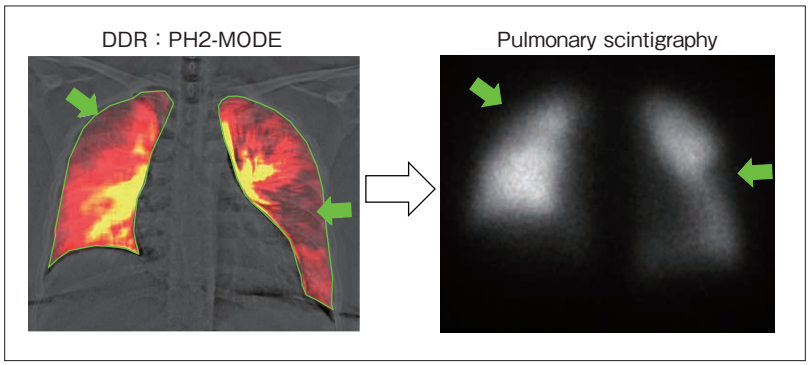

Fig. 4 Application to follow-up of acute pulmonary embolism

In a meta-analysis of 16 papers on the frequency of progression from acute pulmonary embolism to CTEPH, 3.4% of 4,047 pulmonary embolism patients had progressed to CTEPH[2), 3)]. Risk factors include large thrombus, repeated thrombus, and insufficient anticoagulant therapy[3)]. For such patients at high risk of CTEPH, it is useful to use blood flow imaging by DDR as a follow-up after suffering from acute pulmonary embolism[4)].

DDR is available as an option for suspected acute pulmonary embolism, where contrast-enhanced CT is not practical in patients that high radiation exposure or contrast media is contra-indicated, and also as a follow-up for patients at high-risk for CTEPH after acute pulmonary embolism.

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Application of Dynamic Digital Radiography (DDR) imaging to Radiotherapy

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Stereotactic Body Radiation Therapy (SBRT), which irradiates with high doses at pinpoint accuracy to comparatively small solitary lung tumors, is recommended in the Guidelines for Clinical Practice for Lung Cancer as a curative treatment for inoperable stage I-II non-small cell lung cancer. It is very important to accurately assess the volume and pattern of respiratory motion of a tumor before performing a high-precision radiotherapy such as SBRT. In this presentation, I report on the availability of DDR imaging in assessing respiratory motion of lung tumors.

Availability of DDR imaging in Assessment of Respiratory Motion of Lung Tumors

Respiratory gated CT (4D-CT), which is commonly used for assessment of respiratory motion, excels in visibility of tumors, and enables evaluation of arbitrary cross sections, but has several issues, e.g., high radiation exposure, long imaging times, and difficulty in evaluation of patient-specific respiratory patterns. Fluoroscopy using an X-ray simulator is effective but is currently available only to limited medical institutions. We believe that DDR of Konica Minolta is an effective alternative .

DDR has the advantage of being a single system that can provide dynamic imaging when required, but also be practical as a general static imaging equipment. It is also cost-effective and can be utilized not only for radiotherapy treatments but also for general imaging; it is available to a wide variety of medi-

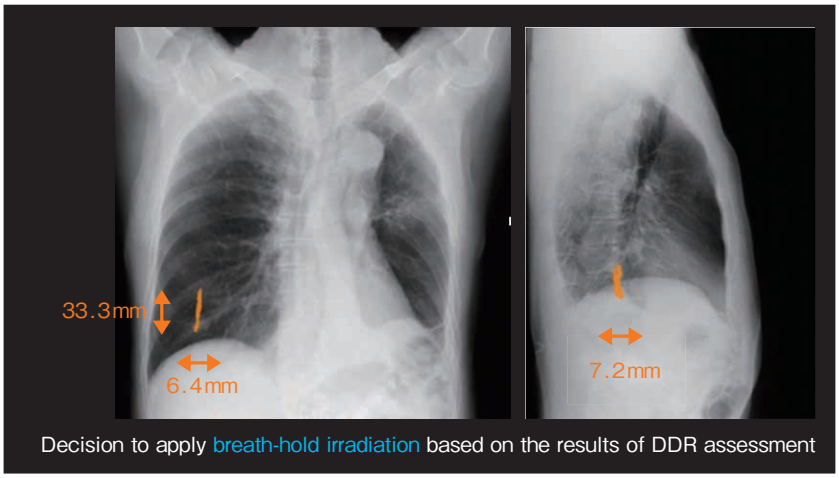

Fig. 1 Case 1: Application of breath-holding protocol

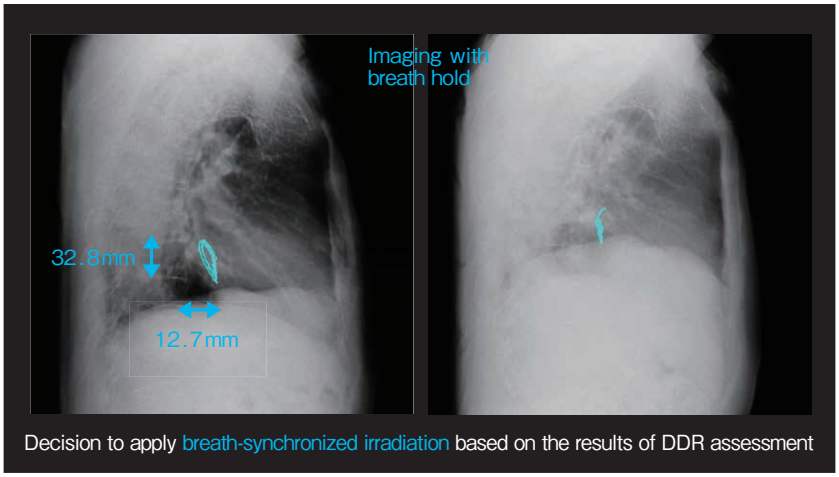

Fig. 2 Case 2: Application of respiratory gated protocol

cal institutions. In addition, DDR images are superior in both sharpness and contrast to fluoroscopic images by an X-ray simulator, and can clearly observe the state of tumor motion due to respiration.

DDR can also quantify tumor mobility. Using "Kinovea", an open-source mobility analysis software, we analyze DDR images, perform automatic tracking for the tumor mobility, and measure its position in the cranio-caudal, sagital, and anteroposterior directions. In phantom experiments, measurements by DDR were highly accurate, being in error by less than 1 mm, and significantly correlated with those by a simulator and by 4D-CT in clinical experiments.

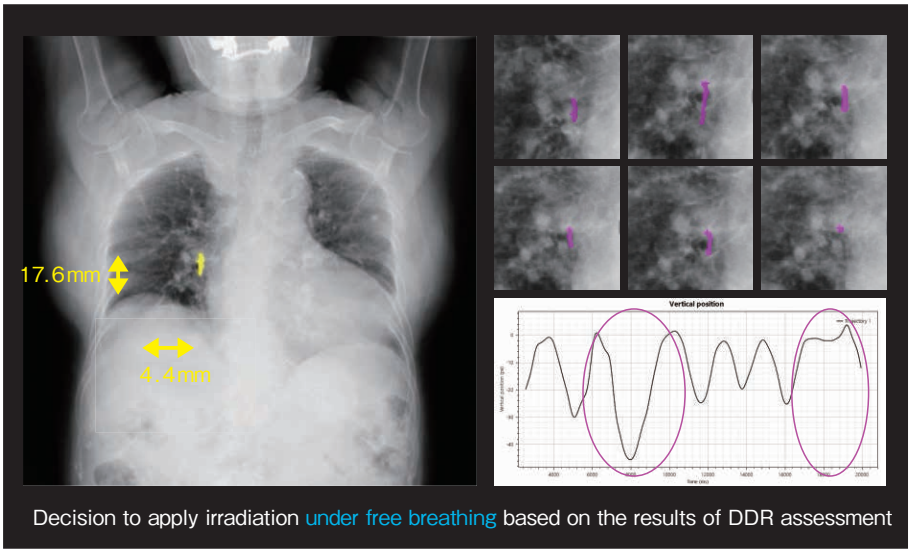

Fig. 3 Case 3: Application of tidal breathing protocol
(Excerpted from Reference Literature 1)

Case Presentation

I will show some cases, where preoperative assessment of SBRT by DDR was useful for determining the radiotherapy strategy.

Case 1 is a 67 y. o. male patient, who had very large motion of the tumor in the right lower lobe, being 33.3 mm in the craniocaudal direction **(Fig. 1).** Targeting the whole mitigation range by the radiotherapy treatment, would result in increased exposure doses to the normal lungs and to the liver, thus breath-holding irradiation was applied in this case.

Case 2 is an 84 y. o. male patient, who had a very large motion of the tumor in the right lower lobe, being 32.8 mm in the craniocaudal direction and 12.7 mm in the anteroposterior direction. Thus, breath-holding irradiation was applied to this case. When the lateral view was taken by DDR with breath hold significant respiratory motion was recognized following poor breath holding, and breath-hold irradiation was judged to be impractical. Respiration-synchronized irradiation was indicated **(Fig. 2)**. It is possible to calculate "Addition of respiration migration countermeasure of the stereotactic radiotherapy treatment" to medical service fees in the case of respiratory gated irradiation and breath holding irradiation. This means that the calculation will be based on the quantitative assessment by DDR.

Case 3 is an 88 y. o. female patient, who had a large motion of the tumor in the right lower lobe, 17.6 mm in the craniocaudal direction. She had a very irregular respiration pattern so that irradiation under free breathing was indicated due to her symptoms **(Fig. 3).**

Thus, it is considered a very big advantage to determine the irradiation method, definitely and early, in the preoperative assessment using DDR.

Improvement in Workflow

If radiotherapy treatment strategy was decided and implemented in the early stage with preoperative assessment using DDR, human and time costs for treatment preparation could be economized, and would also help improve operational workflow. In our hospital, DDR is becoming routinely available as a preoperative examination for SBRT, and at present, all cases receiving SBRT are undergoing DDR.

Summary

Once DDR is introduced to radiotherapy treatment, it becomes possible to perform an examination of high-quality, high-accuracy and quantitative respiration mobility in an efficient workflow regardless of medical institutions. In my speculation, DDR will definitely fulfil any new needs as a new normal modality in the future radiotherapy treatment.

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https://doi.org/10.1002/acm2.13736

Collaboration with Clinical Departments and Imaging Techniques
- as a standard examination

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Our hospital started using Dynamic Digital Radiography (DDR) in clinical practice in May 2020. I describe DDR imaging in terms of its test methods, operations, clinical practice, and clinical research.

Operation of X-ray Dynamic Imaging in Our Hospital

DDR is mainly performed for the chest application. Before starting chest imaging, we usually first explain DDR to the patient and then proceed with the imaging according to the guidance. After imaging is over, we confirm whether there has been a movement corresponding to the width of about 2 ribs on the moving image to understand the degree of deep breathing. Not only the original DDR image but also images from advanced image processing modes such as PL-MODE, LM-MODE, PH-MODE, PH2-MODE are provided via "KINOSIS", which is a workstation dedicated for DDR analysis.

In addition, DDR imaging can also be performed for the neck mainly to observe vocal cord movement in patients suspected of postoperative hoarseness or recurrent laryngeal nerve paralysis. The imaging is performed for a patient in a sitting position according to the Auto Voice while he/she is uttering or having natural breathing **(Fig. 1).** The irradiation field is collimated down to the proper site and requires 10 seconds of imaging time, with the exposure dose of about 1 mGy, which is less than 2 times worth of the exposure dose (0.8 mGy) for the cervical vertebra in DRLs 2020. The image distribution is provided both as an original and in of the FE-MODE. The frame rate is 15 fps for DDR, which is sufficient to enable monitoring of the rapid movement of the vocal cords. FE-MODE enhances the vocal cords even at low exposure doses, and makes it easier to observe minute movements **(Fig. 2).**

Hospital departments, where DDR is available, include the departments of respiratory surgery and internal medicine, circulatory organ internal medicine, radiotherapy treatment of the thorax, and the departments of thyroid gland surgery and otolaryngology for the neck. The department of respiratory surgery accounts for about 70% of use of DDR. Imaging technique protocols vary in the

Fig. 1 Positioning of DDR in the neck

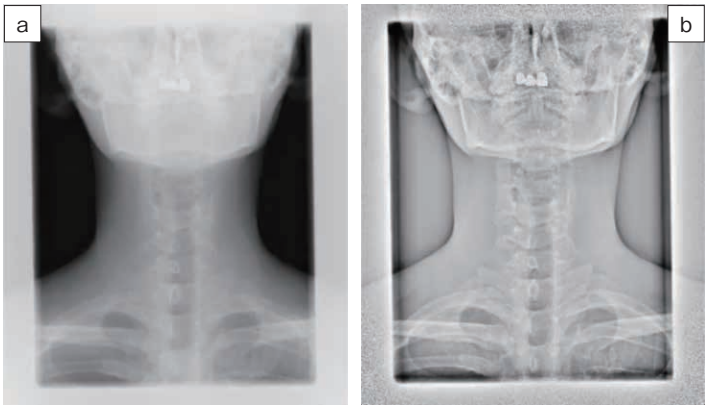

Fig. 2 DDR images in the neck
a: Original b: FE-MODE

departments and was established based on images that doctors from each department had observed and discussed.

The number of imaging exams has reached about 100 cases per month up to now, reaching a total of 1300 cases in 2021. There is a study team, which may contribute to the increased imaging volume. Our hospital initiated a study team for DDR in corporation with Dept. of Respiratory Surgery, Dept. of Radiology, Division of Radiology, as well as Konica Minolta in June 2020, and it has taken up DDR as a common theme, studying target patients and diseases, and promotion of the research. This study team was involved in understanding and communicating knowledge of DDR in the hospital departments at the beginning, and DDR gradually started to become more frequently used in the hospital. At present, the study team meets every 2 or 3 months. In addition to the Dept. of Respiratory Surgery at the beginning, Dept. of Respiratory Internal Medicine, Dept. of Infectious Disease and Dept. of Otolaryngology also have joined the study team.

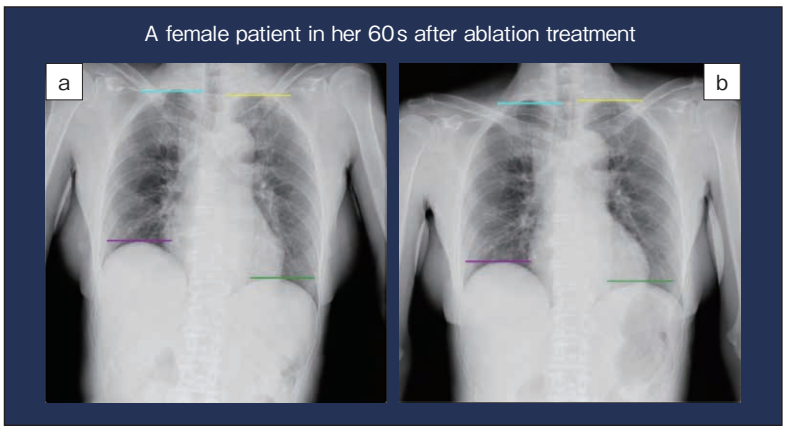

Fig. 3 Analysis of diaphragm movement by DM-MODE
a: 1 month post-operation b: 6 months post-operation

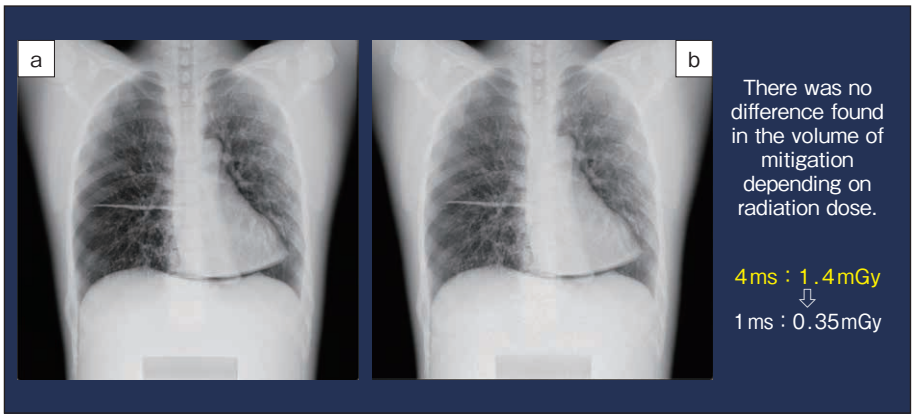

Fig. 4 Analysis of radiation dose reduction by DM-MODE
a: a standard radiation dose b: 1/4 of the standard radiation dose

Relationship between Clinical Practice and Clinical Research

I will describe the clinical practice and clinical research on DDR in our hospital. In the Dept. of Cardiovascular Internal Medicine, DDR are taken after an ablation treatment for auricular fibrillation using a cryoballoon. Cryoballoon treatment may cause transient phrenic nerve palsy. Decreases in diaphragmatic motion can be visualized more clearly in DDR than in static imaging, and changes over time in accordance with respiratory cycles in the recovery period can also be confirmed by quantifying diaphragmatic motion by DM-MODE **(Fig. 3).**

Thus, DM-MODE is a useful test and is expected to be applied to many fields. We wondered if the radiation dose could be further reduced, and focused on DM-MODE. In preparation for the verification, a phantom with vertical movement was made using a chest phantom, a shell for head and neck used in radiotherapy, and a syringe. It was verified how well diaphragm motion analysis can be done with reduced radiation dose in our hospital. Results showed that even at a dose of 1/4 of the standard dose, there was no large change in the visibility of the vertical motion of the phantom, proving the analysis could be done **(Fig. 4).** In DM-MODE, further dose reduction is considered possible.

Summary

Two years have passed since the start of DDR imaging in our hospital, and opportunities for imaging have expanded to various medical care departments. Changing from static image to moving images enables us to monitor the movements of organs, which were not observed in the past, and to obtain much information. Further scale-up of KINOSIS in the future is expected to provide more clinical information from moving images and to expand and improve the utility of DDR.

Exective Remarks

Exective Remarks 1

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

Today, let me express my gratitude to very interesting presentations and active discussions made to the 3 topics: “AeroDR TX m01”, a radiographic apparatus for round visits newly released this year, “DDRAtlas”, which was also released this year, and research in clinical practice.

Until today we took it for granted that images of X-ray portable imaging were rather poor in quality. As shown in Today's presentations and discussions, however, you will surely be able to obtain information, which cannot be obtained via conventional X-ray portable imaging, via AeroDR TX m01, and will most probably expect further development in the future. When wireless data communication technology, such as Wi-Fi high speed communication, advances, and real-time processing using “KINOSIS”, X-ray moving image analysis workstation, becomes realized, there would be a possibility to replace the conventional X-ray equipment for round visits with a new system, which also has the static image function available. We really hope this will dramatically change the concept of X-ray portable imaging.

DDRAtlas, a collection of normal cases as diagnostic criteria of X-ray dynamic image, had been so far introduced in the seminars on X-ray dynamic imaging by last year. This time, its Ver. 1.0 has been opened to the public, which will encourage many investigators to view case images and share their patterns, and thus contribute to the development of new diagnostics. More cases will be accumulated in future, on the basis of which we are expecting the standard diagnosis will be established using Artificial Intelligence (AI).

As to research reports on clinical practice, they have become more substantial in contents and have covered further ranges. This time, we enjoyed listening to, and perceiving, many new possibilities of features of the technologies, such as use of the apparatus for pulmonary embolism, application to Stereotactic Body Radio Therapy (SBRT), example case studies in imaging and a study of radiation doses. There are some reports on the specific field that I did not expect. I am sure that the accumulation of studies and experiments in clinical practice should lead to advances in diagnosis using X-ray dynamic imaging in future.

Exective Remarks 2

Shoji Kudoh, MD, PhD Representative Director, Japan Anti-Tuberculosis Association

Digital cineradiography was developed by Konica Minolta, and was launched in 2018. More than 100 units have already been in operation in the world. At the beginning it was available only in the departments of radiology and respiratory medicine, and then has extended to the fields of respiratory surgery, circulatory medicine, and orthopedics. Since a roentgenographic equipment "AeroDR TX m01" for round visits was released, ICUs and emergency rooms have been involved in its application, and more medical departments are referring to the usefulness of X-ray dynamic imaging. In such a situation, the 4th seminar on X-ray dynamic imaging was held inviting over 800 participants. The presentations were further expanded/improved than those in the last seminar. I have felt all the presentations, as well as the subsequent discussions, were very meaningful and beneficial.

Part 1 took up "AeroDR TX m01" as a special feature for this seminar, which has realized wire-less motion picture imaging. Dr. Kon presented about clinical benefits in patients with pulmonary embolism and novel coronavirus infection (COVID-19). Mr. Takakura reported his experiences in use in the emergency field for workflow, operability and exposure doses, which have suggested a possibility of utilization in ICUs.

In Part 2, Mr. Tsunomori and Dr. Isobe introduced an outline and utilization of "DDRAtlas Ver. 1.0" a digital case collection of dynamic X-ray images, showing that standardization of X-ray dynamic imaging and analysis of normal cases are steadily advancing. X-ray dynamic analysis for a case with emphysema lesion and COVID-19 was reported by Dr. Hayashi.

Part 3 included 3 presentations: Dr. Yamasaki reported clinical application of X-ray dynamic analysis in evaluation of pulmonary circulation, focusing on pulmonary embolism, and showed a possibility of this technology in terms of its usefulness and limit, and blood flow diagnosis, especially positioning in diagnosing pulmonary embolism. Next, Dr. Kitamura made a presentation about a new attempt in application of X-ray dynamic imaging to radiotherapy. Dr. Hashimoto introduced, as a X-ray technologist, how to cooperate with each of the medical departments in expanding usability of X-ray dynamic images, how to challenge for obtaining new information/knowledge, as well as how to learn imaging technique.

During the 4 short years since the launch in 2018, over 100 units of Dynamic Digital Radiography (DDR) have been under operation in domestic and overseas medical fields, with many experiences in use reported in academic societies. In addition, over 40 papers were published at home and abroad; the papers based on the data attributed to Japan are mainly being focused overseas. As far as I have heard, the seminar on X-ray dynamic imaging will be continuously held in future, and additional seminars/workshops are also scheduled targeting users' associations and medical radiology technicians. I think that our future goal is hopefully to apply DDR technology originated in Japan so as to be covered by insurance for a new diagnostic technology. I would like the participants here to lead this technology as key persons representing academic societies in each field, and sincerely hope that this distinguished technology invented in Japan, which has changed the old common sense of "plain roentgenogram should be a static image", will spread extensively all over the world.

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