RAD

Our Experience with Dynamic Chest Radiography Using RADspeed Pro

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1. Hospital Introduction

Seirei Yokohama Hospital **(Fig.1)** is located in Hodogaya Ward, Yokohama City, Kanagawa Prefecture. Its managing body, the Seirei Social Welfare Community, headquartered in Hamamatsu City, Shizuoka Prefecture, is one of the Japan's largest social welfare corporations, operating 213 facilities and 518 projects across one metropolis and seven prefectures. The hospital provides a Care-mix Medical Service System ranging from advanced acute to recovery phase, home care, and palliative care treatments. It was received a business transfer from the National Yokohama East Hospital to the Seirei Social Welfare Corporation in 2001 and opened in 2003. The hospital has 367 beds and employs 20 radiological technologists.

Fig.1 Seirei Yokohama Hospital

2. Equipment Characteristics

For dynamic X-ray radiography, the hospital uses the "RADspeed Pro" diagnostic X-ray system manufactured by Shimadzu Corporation and the portable DR "AeroDR fine" by Konica Minolta. Image analysis and processing are performed on the "KINOSIS" X-ray video analysis workstation. The dynamic digital radiography-capable system is installed in one of the three general radiography rooms and is also used for standard chest and bone radiography, among others **(Fig.2)**.

Fig.2 General radiography room

3. System Features

While conventional X-ray radiography captures static images, dynamic digital radiography acquires sequential radiographs. The setup of the radiography system is similar to that of a general X-ray system, and no special room is required. A significant difference is the use of sequential X-ray pulse irradiation at 15fps for several seconds of radiography. Conventional X-ray radiography requires static images without motion. On the other hand, dynamic digital radiography values images with motion, allowing for functional evaluations previously unattainable with static radiography. This introduces a completely different concept in radiography techniques.

At our hospital, we perform dynamic chest radiography, which includes two types of radiography: under forced breathing and breath-holding. In forced breathing radiography, it is mainly possible to assess the movement of the diaphragm and the extent of adhesions associated with respiration, and to quantify the lung field area through analyzed images. Breath-hold radiography, on the other hand, allows for the observation of changes within the lung field associated with pulsation. Through image analysis and processing, changes in lung marking pixel variation due to pulmonary blood flow can be extracted as changes in lung field density. This allows for the pseudo display of pulmonary blood flow volume.

4. Dynamic Digital Radiography at Our Hospital

At our hospital, dynamic digital radiography is primarily conducted upon the request of the thoracic surgery department. In the framework of Japanese Health Insurance System, imaging solely through dynamic digital radiography is not eligible for insurance reimbursement; therefore, we also capture standard chest radiography in addition to forced breathing and breath-hold radiography. Both forced breathing and breath-hold radiography are taken under breathing instructions, with auto-voice used to ensure reproducibility for both. The RADspeed Pro system introduced at our facility is not only synchronized with the radiation switch but also with the X-ray tube control panel and auto-voice inside the examination room. The synchronization of the X-ray tube control panel and auto-voice within the examination room allows for pre-shooting breathing exercises next to the patient inside the radiography room (Fig.3). The importance of breathing practice for dynamic digital radiography cannot be overstated. The breath-holding needed in dynamic digital radiography is unlike simple breath-holding for less than a second as in general X-ray radiography, successful radiography requires patients to understand the procedure. Therefore, we strive to explain the purpose of dynamic digital radiography and the precautions during examination as clearly and concretely as possible before the breathing practice. The explanation is crucial as patient understanding and cooperation are essential. Patients need to comprehend that unlike static imaging in general X-ray radiography, the results may vary with the quality of their breathing during dynamic imaging. Furthermore, our hospital references pulmonary function test results before the examination. This practice allows us to gauge the respiratory condition of the patient about to be imaged, based on the category determined by the pulmonary function test results, providing a basis for deciding whether a poor examination outcome represents an accurate result for the patient or if re-examination could yield improvement (Fig.4).

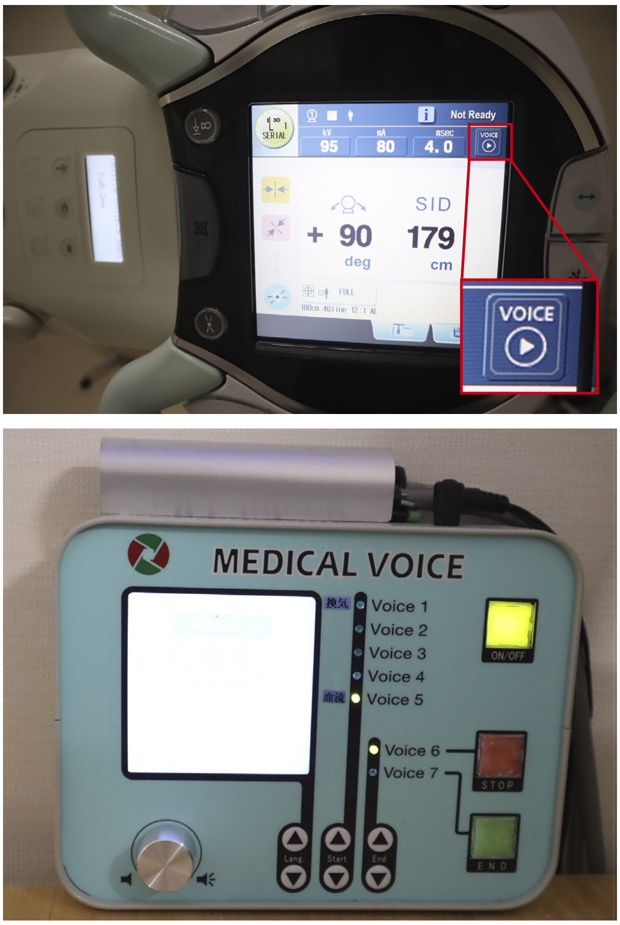

Fig.3 Auto-voice

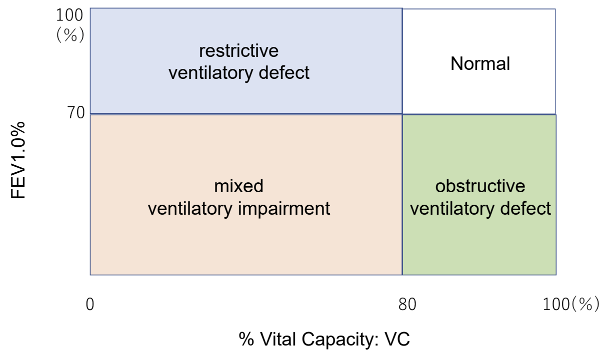

Fig.4 Interpretation of pulmonary function test results

Forced breathing radiography involves capturing images while the patient repeatedly performs deep breathing (Fig.5). In forced breathing radiography, it is crucial to achieve maximum inspiration and expiration. During patient instruction, we initially explain that the process of inhaling and exhaling will be captured as dynamic radiography, showing how the lungs expand and contract. We emphasize the importance of breathing deeply to the limits during inspiration and expiration and maintaining breath-hold to keep the diaphragm still. After listening to the auto-voice once, patients practice breathing under the auto-voice guidance. During this, the radiographer observes whether maximum inspiration, maximum expiration, and breath-holding are performed correctly. Unlike general X-ray radiography, where exposure occurs at maximum inspiratory phase, forced breathing radiography requires timing the exposure to capture the beginning of inspiratory phase. Pressing to the first stage (ready state) starts the auto-voice breathing instructions, and pressing to the second stage (exposure) is timed to coincide with the beginning of inspiratory phase. The auto-voice cues "Inhale~Hold~Exhale~Hold~Inhale" are used to capture both expiratory and inspiratory phases in the dynamic radiography (Fig.6).

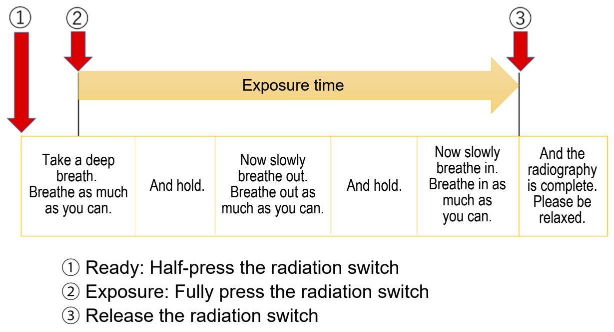

Fig.5 Timing of exposure in forced breathing radiography

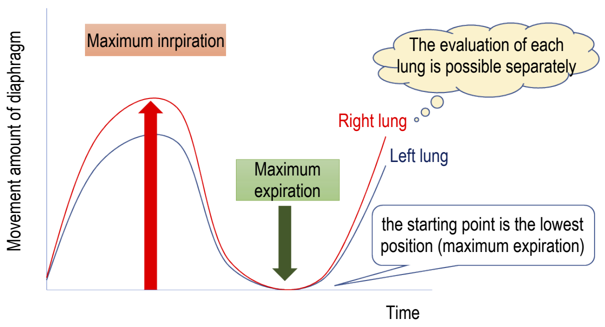

Fig.6 Diaphragm movement with respiratory changes

Next, in breath-hold radiography, radiography is performed with maximum inspiratory level (Fig.7). Just like forced breathing radiography, auto-voice provides breathing instructions for reproducibility. The explanation emphasizes the importance of holding the breath with maximum inspiratory level to keep the diaphragm still. For the timing of the exposure, the process doesn't start immediately after the "Please hold" signal by pressing the second stage of the radiation switch but begins after confirming that the breath has been held. Therefore, the radiographer needs to carefully observe the patient's breathing. The positioning during dynamic

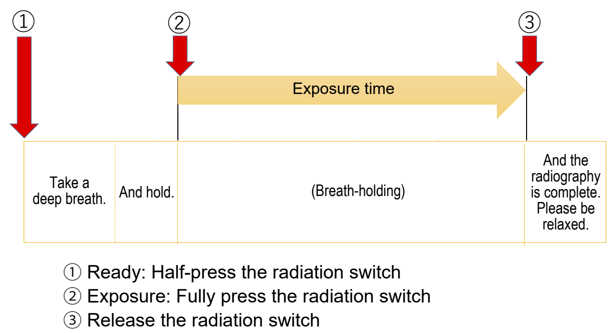

Fig.7 Timing of exposure in breath-hold radiography

digital radiography differs from general chest X-rays, aiming for natural posture during radiography. Hence, positioning that involves moving the scapulae out of the way is avoided, and patients are asked to hold the stand so that the elbow and wrist are parallel. Pelvic stabilization with a belt is used to minimize lateral and anteroposterior movement, which could affect the image analysis. The chin is positioned not too high, just to avoid covering the apical part of the lungs (Fig.8).

Fig.8 Positioning

5. Analysis of Dynamic Digital Radiography

Post-imaging processing is conducted using the Konica Minolta's X-ray Dynamic Digital Radiography Analysis Workstation, KINOSIS. There are eight types of images that can be obtained through analysis processing (Table 1), which can improve the visibility within the lung field, visualize and quantify motion, and extract signal value changes associated with respiration and heartbeats. Most of the images are automatically processed upon being transferred to KINOSIS, except for a few. The dynamic image evaluation mode allows for the automatic measurement of diaphragm excursion and lung field area and quantifying the amount of movement from the dynamic images obtained during deep breathing. Patients with a history of dynamic radiography can reference past images and measurement values from thumbnails. Additionally, the images processed for analysis and the obtained measurement values and graphs can be transferred to PACS, allowing for data reference on the electronic medical record system without going through the client server.

Table 1 Types of Analyzed Images

Type	Image Processing	Effect
Original image	Images during deep breathing or breath-holding	Improvement of visibility within the lung field
BS-MODE	Attenuates clavicle and ribs within the lung field	
FE-MODE	Emphasizes movement of structures (lung tissue) with specific frequencies	
DM-MODE	Quantifies movement of structures such as the diaphragm and displays it graphically	Quantification of movement
PL-MODE	Extracts and displays changes in lung field density due to respiration	Extraction of signal value changes due to respiration and vascular pulsation
PH-MODE	Extracts and displays changes in lung field density due to vascular pulsation	
PH2-MODE	Extracts and displays the amount of change in lung field density due to vascular pulsation	
LM-MODE	Extracts areas of decreased movement within the lung field and displays them with color mapping	Visualization of movement

6. Image Transfer Flow

The captured images are transferred to both PACS and the X-ray Dynamic Digital Radiography Analysis Workstation, KINOSIS. Once post-captured images are transferred to KINOSIS, they are sequentially processed automatically. The analysis is conducted at the KINOSIS client terminal and transferred to the Web and PACS. The analysis results and dynamic images can be referenced via the Web on in-house terminals. Due to their larger size compared to static images, the dynamic images processed for analysis are not transferred to PACS. Instead, chest general radiography, diaphragm tracking point movement graph, lung field area table, and summary images of LM-MODE and PH2-MODE processed for analysis are transmitted to PACS. Image referencing can be done on the in-house PC's Web via shortcuts, without going through the electronic medical record system (Fig.9).

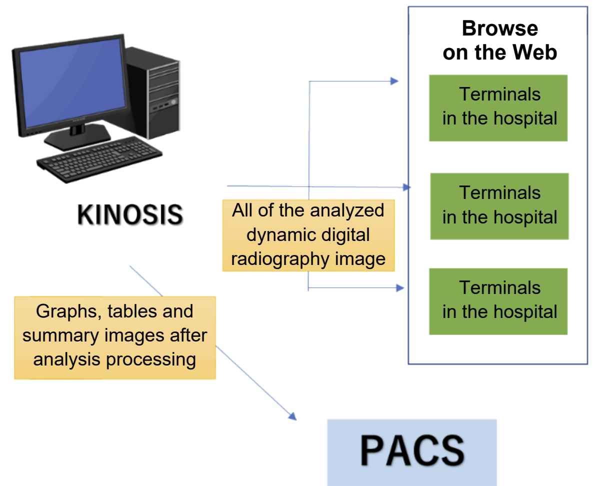

Fig.9 Image transfer flow

7. Radiation Dose Associated with Dynamic Digital Radiography

The diagnostic reference level for chest radiography (posterior-anterior view) according to DRLs2020 is 0.4mGy, and for chest radiography (posterior-anterior + lateral view) according to IAEA guidance levels is 1.9mGy. In our hospital, the total radiation dose (AK value) for chest general radiography, forced breathing radiography, and breath-hold radiography from June 2021 to May 2023, covering 105 cases, averaged 1.88mGy±0.34 (Table 2).

Table 2 Radiation Dose for Dynamic Digital Radiography at Our Hospital

	Chest General Radiography (1R)	Forced Breathing Radiography	Breath-hold Radiography	Total Dose
Average Value (mGy)	0.08 ± 0.06	1.27 ± 0.15	0.56 ± 0.08	1.88 ± 0.34

8. Clinical Application of Dynamic Digital Radiography

Most of the dynamic digital radiography currently performed at our hospital is requested by the thoracic surgery department, primarily for preoperative evaluations of lung cancer and nontuberculous mycobacteria (NTM) infections. The choice of surgical procedure during thoracic surgery changes depending on the presence or absence of adhesions or infiltration. In dynamic images, the lungs move significantly with respiration if there are no adhesions, but if adhesions are present, movement is locally restricted even during respiration. This evaluation of adhesions can be observed in the combination of BS-MODE (Fig.10-1) images, which attenuate bone information within the lung field, and FE-MODE (Fig.10-2) images, processed for frequency, which is called BS×FE-MODE (Fig.10-3). If adhesions are present, an open surgery approach is chosen; without adhesions, a thoracoscopic approach is selected. Moreover, because the movement of lesions within the lung field due to respiration can be captured, the level of ribs for approach can also be determined. Additionally, breath-hold imaging captures changes in pulsatile movement, which is used to predict the volume of intraoperative bleeding. LM-MODE is available to visualize movement (Fig.10-4), tracking

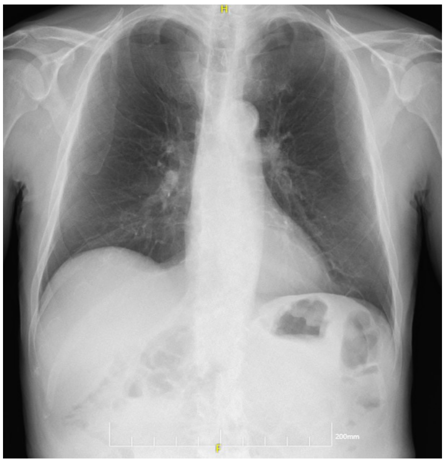

Fig.10-1 BS-MODE

Fig.10-2 FE-MODE

Fig.10-3 BS×FE-MODE

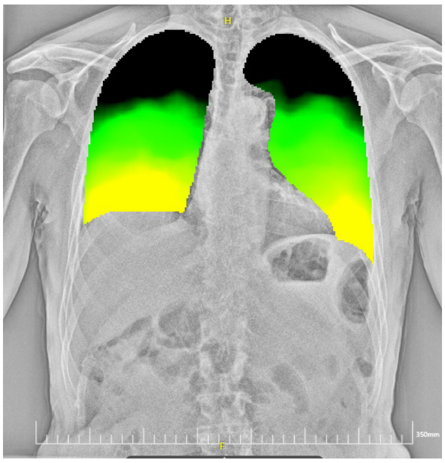

Fig.10-4 LM-MODE

the density pattern within the lung field to visualize the extent of movement (vertical) within the lungs, displayed in a gradient from yellow to black. Green to yellow represents movement in the same direction as the diaphragm, with areas moving less appearing closer to black. Even in normal cases, the apical part of the lungs shows little movement due to respiratory changes, thus appearing black, a phenomenon difficult to observe with traditional CT or MRI. This contributes to improved accuracy in preoperative planning, such as approach methods, strategy, and estimation of operative time. Thus, dynamic digital radiography, which allows continuous observation of movement within the lung field due to respiration, is considered useful in various scenarios.

Many patients undergoing preoperative evaluation also undergo pulmonary function tests, which are the gold standard, classifying respiratory function impairments based on vital capacity and FEV1 results. However, pulmonary function tests assess the function of both lungs together, not each lung separately. In contrast, dynamic analysis allows for the evaluation of each lung separately, which is not possible with pulmonary function tests. Thus, in the surgical field, it aids in approaching techniques, while in the internal medicine field, it enables quantification through analysis, assisting in diagnosis.

Additionally, dynamic digital radiography can be used not only for preoperative evaluations but also for postoperative follow-up, assessing the presence of diaphragmatic paralysis, and comparing preoperative and postoperative states.

9. Future Prospects for Dynamic Digital Radiography at Our Hospital

Currently, dynamic digital radiography at our hospital is limited to chest imaging and is only performed in the standing position. One of our future prospects is to conduct imaging in sitting or supine positions depending on the patient's condition. To achieve this, it is necessary to consider the development of protocols for imaging distances and exposure conditions for positions other than standing. Additionally, the majority of requests currently come from the thoracic surgery department. We aim to expand the use of dynamic digital radiography to respiratory medicine and cardiology departments in the future. The PH2-MODE of analyzed images allows for the visualization of high-frequency signal changes within the lung field that correlate with the heartbeat from images obtained during breath-hold imaging, making it possible to represent minute signal value changes. Furthermore, there are reports that PH2-MODE imaging can be useful in identifying areas of reduced blood flow in chronic thromboembolic pulmonary hypertension (CTEPH), showing promising findings for future applications. We are also hopeful about the potential for evaluating the range of motion in joints and implants in the field of orthopedics.

10. Conclusion

Dynamic digital radiography allows for functional evaluation through video images, in addition to the morphological evaluation offered by static images using existing equipment. This method can be relatively minimally invasive for patients. As dynamic digital radiography is still developing, it has the potential for application across various fields in the future. Expanding its use not only requires knowledge of physiology, functional anatomy, and surgical techniques but also an understanding of current needs. Moving forward, we aim to explore the added value dynamic digital radiography can offer with a broad perspective.