Motion tracking noise reduction: a new fluoroscopic technology for diagnostic bronchoscopy

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Aims and objectives

Introduction

When a peripheral pulmonary lesion (PPL) is detected, surgery, transthoracic needle aspiration (TTNA) or bronchoscopy is usually performed to diagnose. The diagnostic yield of bronchoscopy has improved since the application of radial endobronchial ultrasound (R-EBUS) [1], and American College of Chest Physicians (ACCP) guidelines recommended to use [2]. In contrast, X-ray fluoroscopy has been used with bronchoscopy especially in Japan [3]. Although its demand combined with R-EBUS remains controversial, fluoroscopy certainly has some advantages as follows: a) confirmation of the location between the devices and the PPLs or pleura, b) recognition of the movement of the devices and the PPLs during respiration, c) selection of using optional devices (angulated curette, needle and so on) [4-7]. Namely, fluoroscopy helps safe use of the devices.

On the other hand, while main component of lung is air, chest contains various densities (mediastinum, heart, bones and so on). Additionally, chest fluoroscopy is often influenced by the movement of respiration and heart beat. Therefore, improvement of image quality including noise reduction has been required more than other organs.

In X-ray fluoroscopy systems, recursive filters are used as a noise reduction technique. The main factor of X-ray fluoroscopic image noise is due to the X-ray quantum mottle, and thus, the time direction weighting by a recursive filter can reduce the noise effectively. However, the recursive filter performs weighting on the same coordinates between the frame, and because of this, there is a problem of image lag generation when a moving object is present in the frame (Fig. 1).

Adaptive Noise Reduction (ANR) is a one frame type noise reduction technique developed in order to suppress image lag generation. ANR classifies noise by the surrounding pixel values and the magnitude of the difference. By applying median filters when the difference is large and applying averaging filters when the difference is small, it reduces noise in an effective manner without generating image lags. However, stronger noise reduction effect than the ANR is sometimes required in medical practice. Therefore, to obtain stronger noise reduction effect as for X-ray fluoroscopy systems, weak recursive filter processing before ANR has been performed (ANR + weak recursive filter: ANR +WRF). Due to this, the image lag problem remained not fully solved (Fig. 2).

Motion Tracking Noise Reduction (MTNR) is a new noise reduction technique developed for the purpose of further suppressing image lag generation. In MTNR, the above
mentioned recursive filter is used in combination with ANR, in which the filter is improved to become motion adaptive. Moreover, it is configured so that weighting of the motion adaptive recursive filter and ANR will be adjusted in each area. Since the motion adaptive recursive filter performs time direction weighting while tracking the movement direction of the moving objects, noise can be reduced while suppressing image lag generation even when the object is moving. However, image lags might be generated in the area in which the object is deformed, even when the motion adaptive recursive filter is used. Therefore, image lag estimation processing is used to estimate whether image lags will be generated in each region, and for the area in which image lags are likely to be generated, the MTNR weighting is decreased while the ANR weighting is increased. With the above configuration, MTNR can reduce noise while suppressing the image lags for the entire frame effectively (Fig. 3).

In advance, we performed the basic experiment to validate the image lag and the signal intensity among MTNR, ANR+WRF and conventional recursive filter. We used the phantom which was set the line profile (width 25 pixels x length 60 pixels) (Fig. 4). We slid the phantom with 4 pixels per frame and detected the signal on the line profile.

As a result, no image lags generate in MTNR because of its motion detection processing while image lags generated in other processing when there was motion (Fig. 5). At the same time, the signal intensity was stronger in MTNR than in other processing because signal reduced due to the influence of the recursive.

The image quality of MTNR was estimated superior to existing processing. So, we conducted a retrospective study to verify the clinical performance of MTNR compared to ANR+WRF using diagnostic bronchoscopy cases.

Images for this section:
Fig. 1: Conventional recursive filter can reduce the noise by time direction weighting. However, when a moving object is present in the frame, image lag generates.

Fig. 2: Adaptive Noise Reduction (ANR) reduces noise by applying median filters and averaging filters without generating image lags. However, weak recursive filter processing before ANR (ANR+WRF) has been performed because stronger noise reduction effect is required. Therefore, minor image lag generates caused by recursive filter.

Fig. 3: Motion Tracking Noise Reduction (MTNR) combines motion adaptive recursive filter and ANR. The motion adaptive recursive filter performs time direction weighting while tracking the movement direction of the moving objects. Meanwhile by image lag estimation processing, MTNR weighting is decreased while ANR weighting is increased for the area in which image lags are likely to be generated.
**Fig. 4:** The signal detection experiment using the phantom Figure shows the phantom which was set the line profile (width 25 pixels x length 60 pixels). The phantom was with 4 pixels per frame and the signal was detected on the line profile.
**Fig. 5:** The image lag and the signal intensity of each image processing Image lags generated (arrow head) in ANR+WRF and conventional recursive filter while there were no lags in MTNR. The brightness ratio of MTNR was the lowest (arrow) by overlap without blurring, it meant the signal intensity was the strongest in MTNR. MTNR: motion tracking noise reduction, ANR+WRF: adaptive noise reduction + weak recursive filter.
Methods and materials

Subjects

Ninety three consecutive patients who underwent diagnostic bronchoscopy for PPLs in National Cancer Center Hospital from June to October 2013 were included. All procedures were performed using endobronchial ultrasound with a guide sheath (EBUS-GS), as previously described [1, 8] under the X-ray fluoroscopic guidance (VersiFlex VISTA®, Hitachi, Japan). The raw data of fluoroscopy during the examination were prospectively collected and processed by MTNR and ANR+WRF retrospectively.

PPLs were defined as lung parenchymal lesions without visible endobronchial involvement.

Assessments

Graininess, contrast, sharpness and visibility of the lesion were assessed for each randomly sorted MTNR and ANR+WRF videos by 7 pulmonologists with 3-28 years of bronchoscopic experience blindly. The scores were measured using the continuously-distributed test (minimum 0 to maximum 50).

After that the patients were divided into MTNR predominant group and ANR+WRF predominant group based on the results that the majority of evaluators scored better for each variables.

Statistical analyses

The measured scores of graininess, contrast, sharpness and visibility of the lesion were statistically analyzed using the paired t-test respectively.

The divided MTNR or ANR+WRF predominant group of visibility of the lesion were compared with other variables using univariate and multivariate analyses by logistic regression.

Other variables included follows: lesion size (< 20 mm or > 20 mm); lesion feature (solid or (mixed and pure) ground-glass opacity (GGO); lung field location (upper, middle or lower); overlap with heart or diaphragm (with or without); lesion location in CT (one-third
of the peripheral area or two-thirds of the central area); MTNR or ANR+WRF predominant of graininess, contrast and sharpness. The lesion location was divided based on the study of Baaklini et al [9].

All p values were two-sided, and a p value of < 0.05 indicated statistical significance. All analyses were performed using JMP® (Ver. 10.0.0, SAS Institute Inc., North Carolina, USA).

Results

Median age of included patients were 68 (range 32-87), and 55 (59.1 %) of these were male (Table 1).

Median size of target PPLs were 24.2 (range 10.3-76.4) mm, and 67 (69.9 %) of these had solid feature. In chest X-ray, 23, 37, 33 (24.7, 39.8, 35.5 %) PPLs located in upper, middle and lower lung field, respectively, and 11 (11.8 %) lesions overlapped with heart or diaphragm. Meanwhile in CT, 60 (64.5 %) PPLs located in the peripheral area.

All pulmonologists scored graininess, contrast and visibility of the lesion significantly higher in MTNR based on the paired t-test (Table 2). With respect to sharpness, 6 pulmonologists showed significantly higher scores in MTNR.

Graininess was better using MTNR in all cases (Table 3). The majority of contrast, sharpness and visibility of the lesion also had better scores in MTNR.

Following the univariate analysis for visibility of the lesion, overlap with heart or diaphragm, contrast, sharpness were significant factors (p = 0.008, < 0.001, 0.004, respectively) (Table 4). Meanwhile in the multivariate analysis, contrast and sharpness remained as significant factors (p = 0.022, 0.040, respectively).

Images for this section:
<table>
<thead>
<tr>
<th>Age, median (range)</th>
<th>88 (32–87)</th>
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<tbody>
<tr>
<td>Gender, no. (%)</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>55 (59.1)</td>
</tr>
<tr>
<td>Female</td>
<td>38 (40.9)</td>
</tr>
<tr>
<td>Size (mm), median (range)</td>
<td>24.2 (10.3–78.4)</td>
</tr>
<tr>
<td>≥ 20</td>
<td>65 (69.9)</td>
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<tr>
<td>&lt; 20</td>
<td>28 (30.1)</td>
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<tr>
<td>Feature, no. (%)</td>
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<tr>
<td>solid</td>
<td>67 (72.0)</td>
</tr>
<tr>
<td>GGO</td>
<td>26 (28.0)</td>
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<td>Field, no. (%)</td>
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<tr>
<td>Upper</td>
<td>23 (24.7)</td>
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<tr>
<td>Middle</td>
<td>37 (39.8)</td>
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<tr>
<td>Lower</td>
<td>33 (35.5)</td>
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<tr>
<td>Location, no. (%)</td>
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<tr>
<td>Peripheral</td>
<td>60 (64.5)</td>
</tr>
<tr>
<td>Central</td>
<td>33 (35.5)</td>
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<tr>
<td>Overlap with heart or diaphragm, no. (%)</td>
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<tr>
<td>With</td>
<td>11 (11.8)</td>
</tr>
<tr>
<td>Without</td>
<td>82 (88.2)</td>
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</table>

**Table 1:** Patients characteristics GGO: ground-glass opacity
Table 2: The paired t-test of MTNR and ANR+WRF MTNR: motion tracking noise reduction, ANR+WRF: adaptive noise reduction + weak recursive filter

<table>
<thead>
<tr>
<th>Evaluators (bronchosopic experience)</th>
<th>Graininess</th>
<th>Contrast</th>
<th>Sharpness</th>
<th>Visibility of the lesion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dr. A (18 years)</td>
<td>37.4 / 13.1</td>
<td>35.9 / 19.4</td>
<td>35.4 / 19.7</td>
<td>33.1 / 20.2</td>
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<tr>
<td></td>
<td>(&lt; 0.001)</td>
<td>(&lt; 0.001)</td>
<td>(&lt; 0.001)</td>
<td>(&lt; 0.001)</td>
</tr>
<tr>
<td>Dr. B (28 years)</td>
<td>24.0 / 20.6</td>
<td>24.4 / 22.5</td>
<td>24.2 / 22.4</td>
<td>18.1 / 15.8</td>
</tr>
<tr>
<td></td>
<td>(&lt; 0.001)</td>
<td>(&lt; 0.001)</td>
<td>(0.005)</td>
<td>(&lt; 0.001)</td>
</tr>
<tr>
<td>Dr. C (14 years)</td>
<td>28.9 / 11.0</td>
<td>27.5 / 18.0</td>
<td>26.8 / 19.1</td>
<td>28.1 / 24.3</td>
</tr>
<tr>
<td></td>
<td>(&lt; 0.001)</td>
<td>(&lt; 0.001)</td>
<td>(&lt; 0.001)</td>
<td>(&lt; 0.001)</td>
</tr>
<tr>
<td>Dr. D (5 years)</td>
<td>33.4 / 21.3</td>
<td>30.1 / 26.9</td>
<td>31.3 / 25.1</td>
<td>30.3 / 24.8</td>
</tr>
<tr>
<td></td>
<td>(&lt; 0.001)</td>
<td>(&lt; 0.001)</td>
<td>(&lt; 0.001)</td>
<td>(&lt; 0.001)</td>
</tr>
<tr>
<td>Dr. E (4 years)</td>
<td>30.3 / 21.9</td>
<td>27.2 / 24.6</td>
<td>26.9 / 25.4</td>
<td>31.1 / 28.8</td>
</tr>
<tr>
<td></td>
<td>(&lt; 0.001)</td>
<td>(&lt; 0.001)</td>
<td>(0.004)</td>
<td>(&lt; 0.001)</td>
</tr>
<tr>
<td>Dr. F (3 years)</td>
<td>32.8 / 15.1</td>
<td>27.0 / 21.5</td>
<td>24.3 / 23.5</td>
<td>24.6 / 20.5</td>
</tr>
<tr>
<td></td>
<td>(&lt; 0.001)</td>
<td>(&lt; 0.001)</td>
<td>(0.249)</td>
<td>(&lt; 0.001)</td>
</tr>
<tr>
<td>Dr. G (4 years)</td>
<td>31.2 / 20.4</td>
<td>29.4 / 23.2</td>
<td>29.2 / 25.6</td>
<td>30.4 / 25.5</td>
</tr>
<tr>
<td></td>
<td>(&lt; 0.001)</td>
<td>(&lt; 0.001)</td>
<td>(&lt; 0.001)</td>
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</table>

Table 3: The majority of the better scores MTNR: motion tracking noise reduction, ANR + WRF: adaptive noise reduction + weak recursive filter

<table>
<thead>
<tr>
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<th>MTNR predominant [n (%)]</th>
<th>ANR+WRF predominant [n (%)]</th>
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<tbody>
<tr>
<td>Graininess</td>
<td>93 (100.0)</td>
<td>0 (0.0)</td>
</tr>
<tr>
<td>Contrast</td>
<td>80 (86.0)</td>
<td>13 (14.0)</td>
</tr>
<tr>
<td>Sharpness</td>
<td>76 (81.7)</td>
<td>17 (18.3)</td>
</tr>
<tr>
<td>Visibility of the lesion</td>
<td>77 (82.8)</td>
<td>16 (17.2)</td>
</tr>
</tbody>
</table>
Table 4: The univariate and multivariate analyses for visibility of the lesion MTNR: motion tracking noise reduction, ANR+WRF: adaptive noise reduction + weak recursive filter, GGO: ground-glass opacity, NA: not applicable
Conclusion

Discussion

In this study, we verified the clinical performance of Motion Tracking Noise Reduction (MTNR). MTNR is a new noise reduction technique developed for suppressing image lag generation by the combination of motion adaptive recursive filter (temporal filter) and Adaptive Noise Reduction (ANR) (spatial filter).

All pulmonologists scored graininess significantly higher in MTNR than in ANR+WRF as expected. As shown in the representative case (Fig. 6), MTNR had obviously better graininess than ANR+WRF in all cases.

Meanwhile, the majority of contrast and sharpness also had better scores in MTNR. It is known that there are trade-off relationship between these two factors and graininess. However in our study, three major factors of image quality improved at the same time. This is why MTNR showed sufficiently high graininess even in the course of gradation processing to keep the background density constant (enough contrast), so these factors were compatible well in MTNR.

While MTNR also led better visibility of the lesion in most cases, ANR+WRF showed better visibility than MTNR in some cases. Following the multivariate analysis, contrast and sharpness were significant factors. As a matter of course, it means image quality influenced for visibility of the lesion. Moreover as another factor, overlap with heart or diaphragm was significant in the univariate analysis although it was not significant in the multivariate analysis. Actually, some these cases showed worse visibility in MTNR conversely as shown in the representative case (Fig. 7). One of the reason, it is considered possible that the above mentioned gradation processing adversely affected. The processing emphasizes the contrast as a reference to the background density. However, solid structure like heart and diaphragm are found in high density originally, so the lesion might be hidden due to further high density by the processing.

Lesions located in the basal segments there overlapped with diaphragm has been reported to be difficult to diagnose under X-ray fluoroscopy [10, 11]. For these lesions, introduction of the adjusted gradation processing considering the relationship with the density of surrounding structures will expect to solve this problem.

Limitations
The current study had several limitations. First, the study was a retrospective and single-institution study. Second, we did not evaluate using receiver operating characteristic (ROC) curve which is known as a standard test for evaluating the performance of the equipment [12]. Because we always pay attention to squeeze the radiographing range around the target to reduce X-ray exposure, so we could not prepare normal cases without lesions. Third, we assessed the visibility of the lesion without specifying its location. As with ROC curve, there might be some cases that evaluators checked a false other structure as PPL.

**Conclusion**

MTNR improved the image qualities and the visibility of the lesion. MTNR is useful processing for bronchoscopy under X-ray fluoroscopy.

**Images for this section:**
**Fig. 6:** The solid nodule 25.2 mm in size was located in left middle lung field (arrow head). MTNR (right image) had obviously better graininess than ANR+WRF (left image). And visibility of the lesion was also better in MTNR.

![Image of Fig. 6](image)

**Fig. 7:** The solid nodule 20.8 mm in size was located in right lower lung field overlapped with diaphragm (arrow head). MTNR (right image) had better graininess than ANR+WRF (left image). But visibility of the lesion was better in ANR+WRF because concentrations of the lesion and the diaphragm were too similar to be distinguished.

![Image of Fig. 7](image)
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