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Original Research

## Differentiation between suture recurrence and suture granuloma after pulmonary resection for lung cancer by diffusion-weighted magnetic resonance imaging or FDG-PET / CT <sup>☆</sup>

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### ABSTRACT

There has been no publication which supports the usefulness of DWI differentiating for suture recurrence and suture granuloma after resection for lung cancer. We presented efficacy of DWI or FDG-PET/CT for an assessment of suture lesions after resection for lung cancer. Thirteen suture recurrences and 15 suture granulomas were examined. There were 24 adenocarcinomas and 4 squamous cell carcinomas, and 26 partial resections and 2 segmentectomies. The period of time ( $907 \pm 907$  days) between surgery and suture recurrence was not significantly longer than that ( $546 \pm 547$  days) between surgery and suture granuloma. Diffusion detectability scores (a 5-point scale) of suture recurrences was significantly higher than that of suture granulomas. The ADC value ( $1.35 \pm 0.24 \times 10^{-3} \text{mm}^2/\text{sec}$ ) of suture recurrences was significantly lower than that ( $1.85 \pm 0.60 \times 10^{-3} \text{mm}^2/\text{sec}$ ) of suture granulomas. The SUVmax ( $6.1 \pm 5.0$ ) of suture recurrences was not significantly higher than that ( $4.2 \pm 2.5$ ) of suture granulomas. The sensitivity of 85% (11/13) with DWI was not significantly higher than 69% (9/13) with FDG-PET/CT for suture recurrences. The specificity of 73% (11/15) with DWI was not significantly higher than the 60% (9/15) with FDG-PET/CT for suture granulomas. The accuracy of 79% (22/28) with DWI was not significantly higher than that of 64% (18/28) with FDG-PET/CT for suture recurrences and granulomas. DWI can differentiate suture granuloma from suture recurrence after resection of lung cancer. DWI is more useful than FDG-PET/CT for the differentiation between suture recurrence and suture granuloma after resection for lung cancer.

### 1. Introduction

Lung cancer is one of the leading causes of cancer-related deaths and has many patterns of progression and treatment responses. Suture recurrences after a limited resection for lung cancer have been increasing [1,2]. Suture recurrences after surgery of cancer were detected by FDG-PET/CT and were problems for treatment [3]. On the other hand, suture granulomas developed at the surgical margin of neoplasms were

also reported [4]. A suture granuloma was reported to be false-positive by FDG-PET/CT [5,6]. It is difficult to determine whether new suture lesions after pulmonary resection for lung cancer can be differentiated for benignity or malignancy by CT or PET-CT [6,7]. When there was an FDG uptake at the suture site after resection of cancer, the possibility of postoperative suture granuloma should be considered [8,9]. We have to avoid unnecessary operations for suture granuloma. We reported that diffusion-weighted magnetic resonance imaging (DWI) was a useful ex-

**Abbreviations:** ADC, apparent diffusion coefficient; CT, computed tomography; DWI, diffusion-weighted magnetic resonance imaging; FDG-PET/CT, fluoro-2-deoxy-glucose positron emission tomography-computed tomography; MRI, magnetic resonance imaging; OCV, optimal cutoff value; ROC, receiver operating characteristics; SUVmax, maximum standardized uptake value.

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amination for the detection of recurrence or metastasis from lung cancer [10]. To our knowledge, there has been no publication which supports the usefulness of DWI differentiating for suture recurrence and suture granuloma after pulmonary resection for lung cancer. DWI has been used to detect the restricted diffusion of water molecules. The principles of DWI utilizes the random motion of water molecules in biological tissues [11]. Its apparent diffusion coefficient (ADC) value shows a quantitative parameter of the diffusion of water molecules in biological tissues, and is usually significantly lower in malignant tumors compared with normal tissues or benign lesions [12]. DWI holds great potential for monitoring treatment response in cancer patients shortly after initiation of radiotherapy [13].

In this paper, we presented diagnostic efficacies of DWI or FDG-PET/CT for an assessment of new suture lesions after pulmonary resection for lung cancer.

## 2. Materials and methods

### 2.1. Eligibility

The Institutional Review Board in Kanazawa Medical University approved our study for examining patients with thoracic diseases with DWI and FDG-PET/CT (the approval number: No. I302). Due to contraindication some patients with metal or pacemakers in their body or tattoos did not qualify for the study. After explaining the risks and benefits of the study informed consent was obtained from each participating patient.

### 2.2. Patients

During 8 years from Jan 2010 to Dec 2017, there were 17 pneumonectomies, 9 bilobectomies, 347 lobectomies, 31 segmentectomies and 117 partial resections for patients with lung cancer.

The patients who underwent a partial resection or a segmentectomy for lung cancer, and had a new suture lesion which was examined by magnetic resonance diffusion weighted imaging (DWI) and FDG-PET/CT were enrolled in this study. Finally 28 patients (19% of patients with a segmentectomy or a partial resection) were enrolled in this study (Table 1). For the follow-up after pulmonary resection, CT examinations were performed every 6 months, DWI and FDG-PET/CT were performed when a new lesion was developed. There were 18 males and 10 females, and their mean age was 74 years (range 57 - 85). There were 24 adenocarcinomas and 4 squamous cell carcinomas. There were 26 partial resections and 2 segmentectomies.

### 2.3. Magnetic resonance imaging (MRI)

All MR images were produced with a 1.5 T superconducting magnetic scanner (Magnetom Avanto; Siemens, Erlangen, Germany) with

**Table 1**  
Patients characteristics and previous records of operation.

Age	64 - 85	Mean 68
Sex	male	18
	Female	10
Cell type	Adenoca.	24
	Squamous cell ca.	4
Operation	Partial resection	26
	Segmentectomy	2
Pathological T	T1a	6
	T1b	12
	T1c	3
	T2a	5
	T2b	2
Pathological stage	IA1	6
	IA2	12
	IA3	3
	IB	5
	IIA	2

two anterior six-channel body phased-array coils and two posterior spinal clusters (six-channels each). The conventional MR images consisted of a coronal T1-weighted spin-echo sequence and coronal and axial T2-weighted fast spin-echo sequences. DWIs using a single-shot echo-planar method were applied with slice thickness of 6 mm under SPAIR (spectral attenuated inversion recovery) with respiratory triggered scan with the following parameter: TR/TE/flip angle, 3000–4500/65/90; diffusion gradient encoding in three orthogonal directions; b value = 0 and 800 s/mm<sup>2</sup>; field of view, 350 mm; matrix size, 128 × 128. After image reconstruction, a 2-dimensional (2D) round or elliptical region of interest (ROI) was drawn on the lesion which was detected visually on the ADC map with reference to T2-weighted or CT image by a radiologist (M.D.) with 25 years of MRI experience who was unaware of the patients' clinical data. The procedure was repeated three times and the minimum ADC value was obtained. The radiologist (M.D.) and one pulmonologist (K.U.) with 28 years of experience evaluated the MRI data. They eventually reached the same consensus. When a positive diffusion was identified on DWI, diffusion detectability scores were classified with a variation of the Soo Yeon Hahn model on a 5-point scale as follows: 1=not detectable, 2=slightly detectable, 3=fairly detectable, 4=moderately detectable, and 5=Highly detectable. [7] (Fig. 1).

### 2.4. FDG-PET / CT

FDG-PET scanning was performed with a dedicated PET camera (SIEMENS Biograph Sensation 16, Erlangen Germany) before surgery. All patients fasted for 6 h before scanning. The dose of <sup>18</sup>F-FDG administered was 3.7MBq/Kg of body weight. After a 60- min uptake period, an emission scan was acquired for 3 min per bed position and a whole-body scan (from head to pelvis) was performed. After image reconstruction, a 2-dimensional (2D) round region of interest (ROI) was drawn on a slice after visual detection of the highest count on the fused CT image by a radiologist (N.W.) with 29 years of radioisotope scintigraphy and PET-CT experience who was unaware of the patients' clinical data. For the lesions with negative or faintly positive PET findings, the ROI was drawn on the fusion image with the corresponding CT. From those ROI, the maximum standardized uptake value (SUVmax) was calculated.

### 2.5. Pathological finding and clinical diagnosis

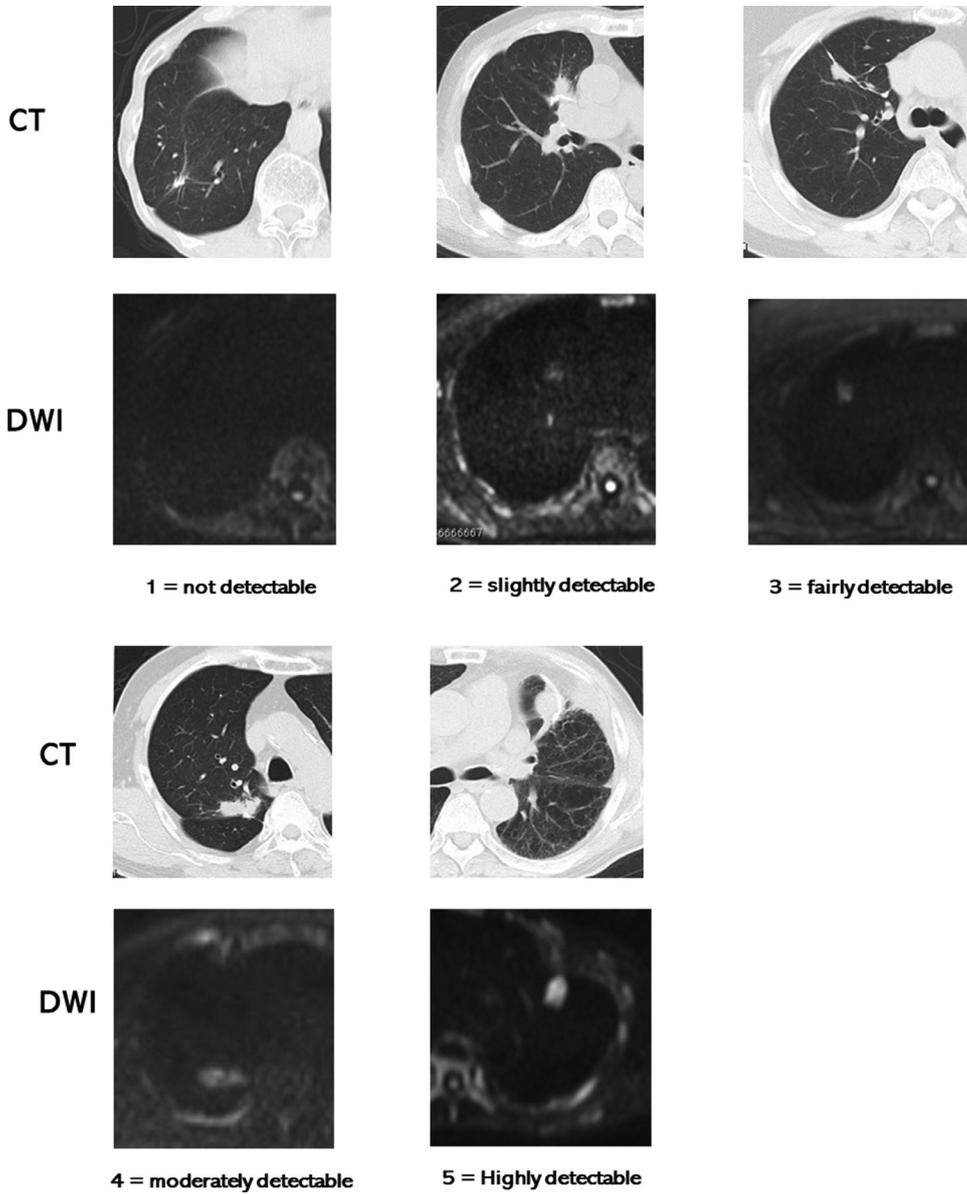
All the suture recurrences were confirmed by bronchoscopic examination or additional resection. Suture granulomas were judged based on pathology or a decrease in size during follow-up examinations.

### 2.6. Statistical analysis

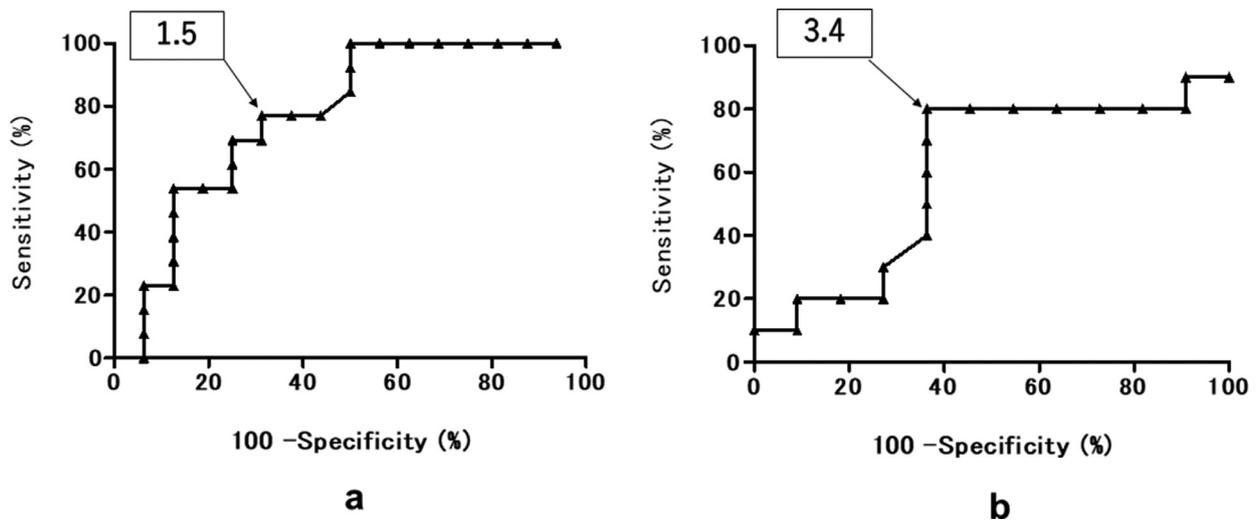
The data is expressed as the mean ± standard deviation. A two-tailed Student t-test was applied for comparison of values. Chi-square test was used for comparison of ratios. A receiver operating characteristics curve (ROC curve) was constructed according to the ADC value and SUV max using GraphPad Prism (Version 5.02, GraphPad Software, Inc. La Jolla, CA, USA), and the cutoff values for a differential diagnosis were determined. The sensitivity, specificity, and accuracy of DWI versus FDG-PET/CT for suture lesion after resection of lung cancer were compared using the McNemar test. The statistical analyses were performed using the computer software program StatView for Windows (Version 5.0; SAS Institute Inc. Cary, NC, USA). A P value of < 0.05 was considered statistically significant.

## 3. Results

The ROC curve for the ADC value for differential diagnosis of suture lesions in DWI revealed the optimal cutoff value was  $1.5 \times 10^{-3} \text{mm}^2/\text{sec}$  (Fig. 2a). The ROC curve for the SUVmax for differential diagnosis of suture lesions in FDG-PET/CT revealed the optimal cutoff value was 3.4 (Fig. 2b).



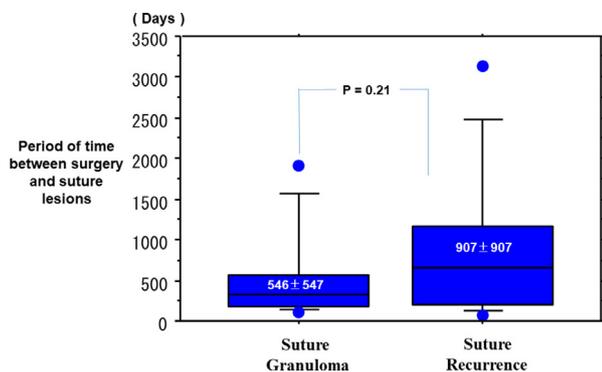
**Fig. 1.** Diffusion detectability scores were classified with a variation of the Soo Yeon Hahn model on a 5-point scale as follows: 1=not detectable, 2=slightly detectable, 3=fairly detectable, 4=moderately detectable, and 5=Highly detectable [7].



**Fig. 2.** a: The ROC curve for the ADC value for differential diagnosis of suture lesions in DWI: the optimal cutoff value  $1.5 \times 10^{-3} \text{mm}^2/\text{sec}$ . Area under the ROC curve: 0.772. b: The ROC curve for the SUVmax for differential diagnosis of suture lesions in PET-CT: the optimal cutoff value 3.4. Area under the ROC curve 0.596.

**Table 2**  
Patients characteristic based on suture lesions.

		Suture granuloma	Suture recurrence	Total cases
Sex	Male	10	8	18
	Female	5	5	10
Cell type	Adenocarcinoma	13	11	24
	Squamous cell ca.	2	2	4
Operation	Partial resection	13	13	26
	Segmentectomy	2	0	2
p Stage	IA1	4	2	6
	IA2	6	6	12
	IA3	2	1	3
	IB	3	2	5
	IIA	0	2	2
Size of suture lesion (mm)		(mean±S.D.) 18.5 ± 8.3	(mean±S.D.) 24.8 ± 12.9	p = 0.19

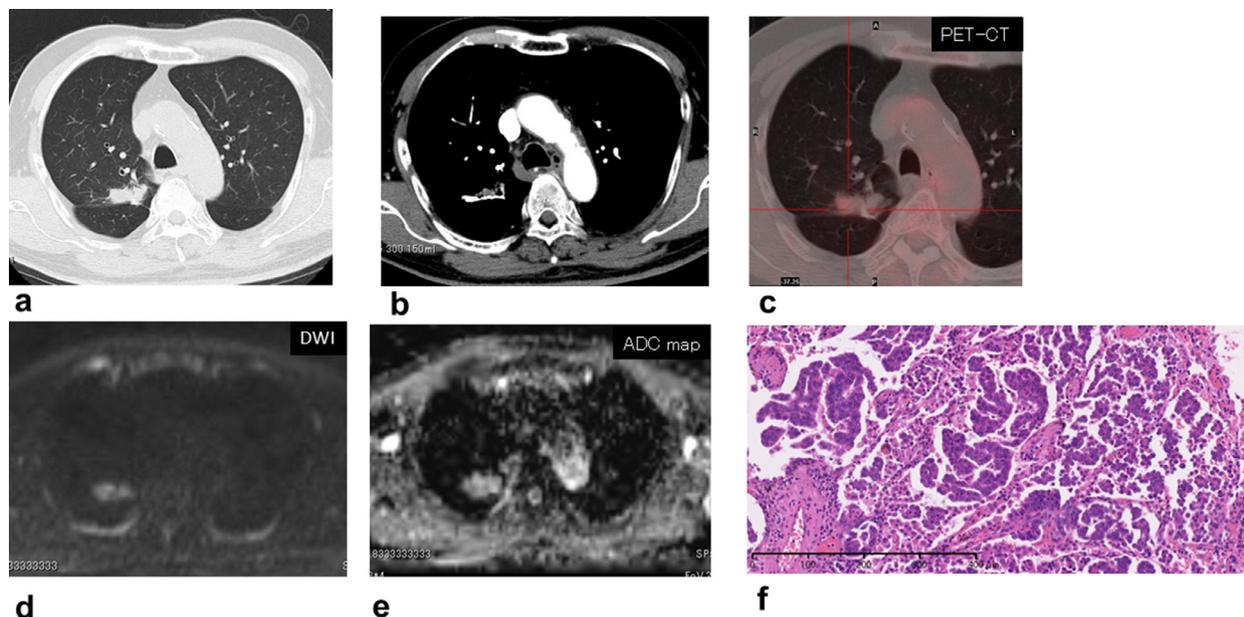


**Fig. 3.** Difference of period between operation and suture shadow onset based on suture recurrence or suture granuloma. The period of suture recurrence (907±907 days) was likely to be longer than that (546±447 days) of suture granuloma, but there were no significant differences ( $p = 0.21$ ).

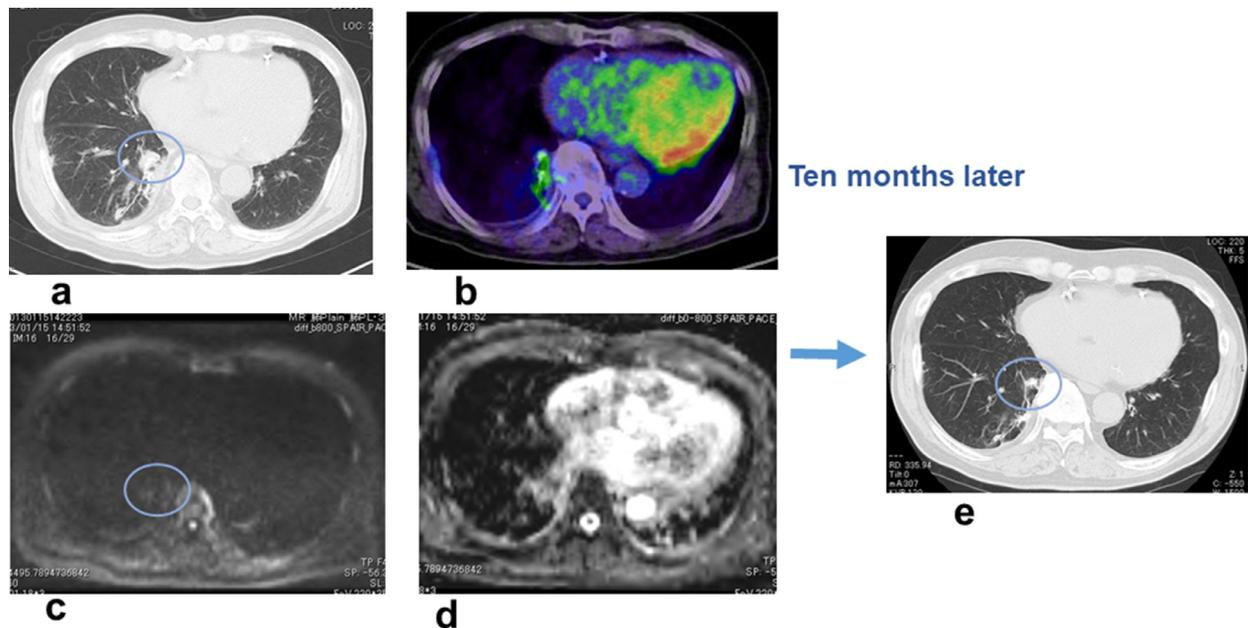
In 28 suture lesions after pulmonary resection of lung cancer, 13 lesions of suture recurrences were confirmed by bronchoscopic examination or additional resection. The remaining 15 suture lesions were judged as suture granuloma based on bronchoscopic examinations or

a decrease in size during follow-up (Table 2). There were no significant differences in sex, cell type, operation and pStage between suture granulomas and suture recurrences. The size of suture lesions were 10 to 48 mm (21±11 mm). Lesion sizes (24.8 ± 12.9 mm) of suture recurrences were likely to be larger than that (18.5 ± 8.3 mm) of suture granulomas, but there were no significant differences ( $P = 0.19$ ). Period of time (907±907 days) between surgery and suture recurrence was likely to be longer than (546 ± 547 days) between surgery and suture granuloma, but there were no significant differences ( $P = 0.21$ ) (Fig. 3).

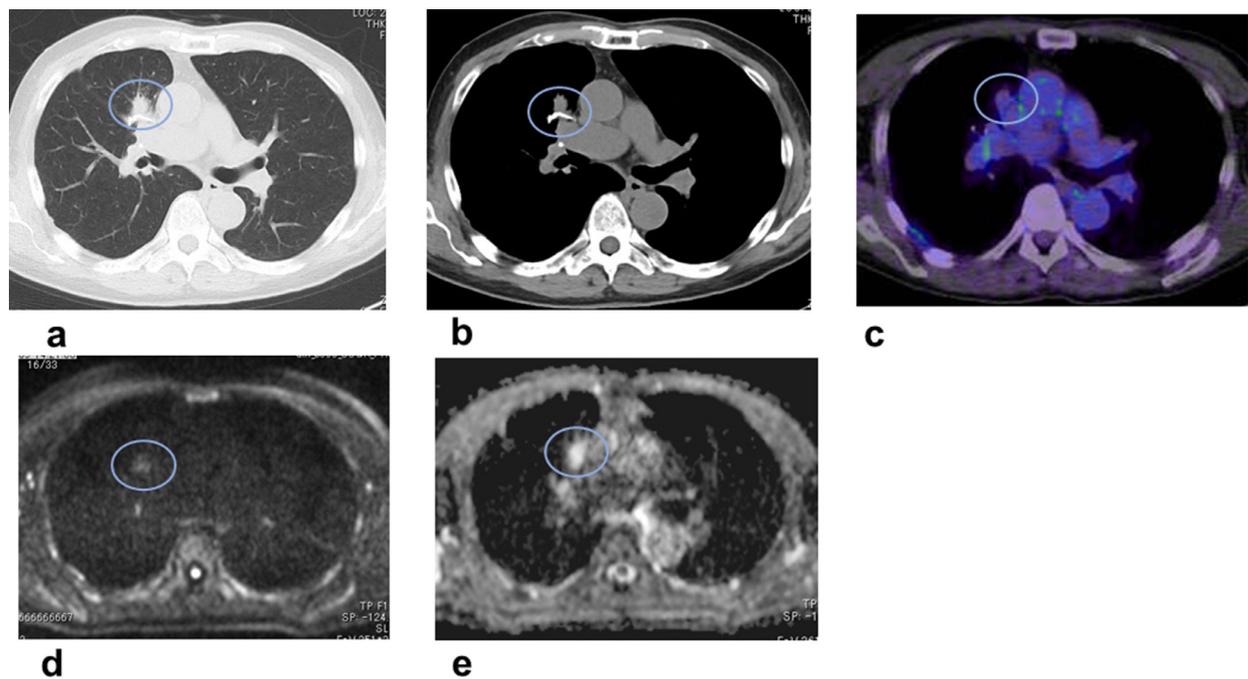
Several cases are presented in Figs. 4–6. In Fig. 4, a 67 year-old male underwent partial resection of right upper lobe for adenocarcinoma. One year and 10 months after the resection, a new shadow at the suture had developed. Its DWI diffusion detectability score was “moderately detectable,” and the ADC was  $1.464 \times 10^{-3} \text{mm}^2/\text{sec}$  on ADC map, meeting malignancy requirements. A right upper lobectomy was performed and it was revealed to be a suture recurrence of adenocarcinoma. In Fig. 5, a 78 year-old male underwent partial resection of the right lower lobe (S10) for squamous cell carcinoma. A new shadow at the suture (S10) showed “slightly detectable” on the diffusion detectability score. The ADC was  $2.079 \times 10^{-3} \text{mm}^2/\text{sec}$  on the ADC map, meeting benignity requirements. The new shadow had decreased in size in 10 months and judged to be a suture granuloma. In Fig. 6, a 70 year-old male under-



**Fig. 4.** A 67 year-old male underwent partial resection of right upper lobectomy for adenocarcinoma. One year and 10 months after the resection, a new shadow at the suture developed and a right upper lobectomy was performed and it revealed a suture recurrence of the adenocarcinoma. a, b: CT showed a new lesion at the suture. c: PET-CT showed a slight accumulation (SUVmax 4.1) of FDG. d: Diffusion detectability score was “moderately detectable”. e: ADC was  $1.464 \times 10^{-3} \text{mm}^2/\text{sec}$  on ADC map. f. HE stain of the suture recurrence (adenocarcinoma).



**Fig. 5.** 78 year-old male underwent partial resection of right lower lobe (S10) for squamous cell carcinoma. a: A new shadow at the suture (S10) on CT. b: The lesion had SUVmax of 4.84 in FDG-PET/CT. c: The shadow was only slightly visible on DWI thus scoring “slightly detectable” on the diffusion detectability score. d: ADC of the suture was  $2.079 \times 10^{-3} \text{ mm}^2/\text{sec}$  on ADC map. e: The new shadow had decreased in size in 10 months and judged to be a suture granuloma.



**Fig. 6.** A 70 year-old male underwent right S3 segmentectomy for adenocarcinoma. Five months after the resection, a new shadow at the suture had developed on CT (a,b) and FDG-PET/CT (c). d: classifying this as “slightly detectable” on the diffusion detectability score. e: ADC of the shadow at the suture was  $2.612 \times 10^{-3} \text{ mm}^2/\text{sec}$  on ADC map. The new shadow at the stump had decreased in size, and judged as a suture granuloma.

went right S3 segmentectomy for adenocarcinoma. Five months after the resection, a new shadow (S3) at the suture had developed, classifying this as “slightly detectable” on the diffusion detectability score. The shadow at the suture showed  $2.612 \times 10^{-3} \text{ mm}^2/\text{sec}$  on ADCmap, meeting benignity requirements. The shadow at the suture had decreased in size and judged to be a suture granuloma.

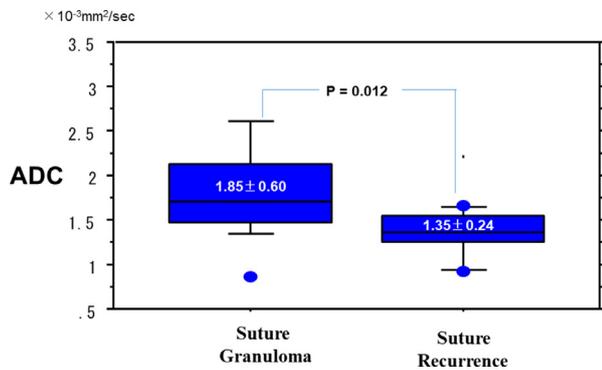
Diffusion detectability cores based on suture lesions were presented in Table 3. For 13 lesions of suture recurrence, there were 8 lesions of a 5 “highly detectable”, 4 lesions of a 3 “fairly detectable” and 1

lesion of a 4 “moderately detectable” On the other hand, for the remaining 15 lesions of suture granuloma, there were 8 lesions of a 2 “slightly detectable”, 3 lesion of a 1 “not detectable,” 2 lesions of a 3 “fairly detectable, 1 lesion of a 4 “moderately detectable” and 1 lesion of a 5 “highly detectable.” The diffusion detectability scores of the 13 lesion of suture recurrence was a significantly higher than that of the 15 lesions of suture granuloma in Chi-square test ( $p = 0.0019$ ). The ADC value ( $1.35 \pm 0.24 \times 10^{-3} \text{ mm}^2/\text{sec}$ ) of the 13 suture recurrences was significantly lower than that ( $1.85 \pm 0.60 \times 10^{-3} \text{ mm}^2/\text{sec}$ ) of the 15 suture

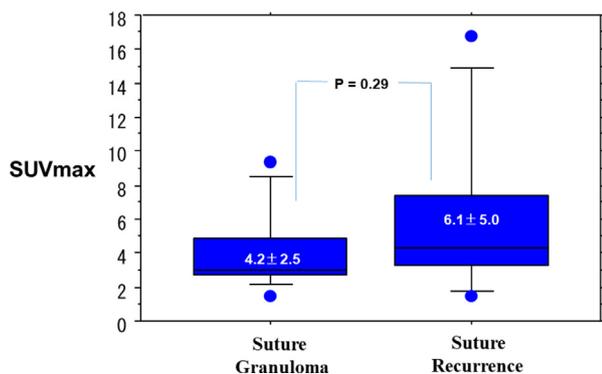
**Table 3**  
Diffusion detectability cores based on malignancy or benignity.

Suture lesion	Diffusion detectability					Total cases
	1 not detectable	2 slightly detectable	3 fairly detectable	4 moderately detectable	5 highly detectable	
recurrence	0	0	4	1	8	13
granuloma	3	8	2	1	1	15
Total cases	3	8	6	2	9	28
	9				recurrence	
	8	granuloma			recurrence	
	7	granuloma			recurrence	
	6	granuloma	recurrence		recurrence	
	5	granuloma	recurrence		recurrence	
	4	granuloma	recurrence		recurrence	
	3	granuloma	recurrence		recurrence	
	2	granuloma	granuloma	recurrence	recurrence	
	1	granuloma	granuloma	granuloma	granuloma	

Chi-square test  $p = 0.0019$ .



**Fig. 7.** Difference of ADC value between suture granuloma and suture recurrence of lung cancer. ADC value ( $1.35 \pm 0.24 \times 10^{-3} \text{ mm}^2/\text{sec}$ ) of suture recurrence was significantly lower than that ( $1.85 \pm 0.60 \times 10^{-3} \text{ mm}^2/\text{sec}$ ) of suture granuloma ( $P = 0.012$ ).



**Fig. 8.** Difference of SUVmax between suture granuloma and suture recurrence. SUVmax ( $6.1 \pm 5.0$ ) of suture recurrence was likely to be higher than that ( $4.2 \pm 2.5$ ) of suture granuloma, but there were no significant differences ( $P = 0.29$ ).

granulomas ( $P = 0.012$ ) (Fig. 7). The SUVmax ( $6.1 \pm 5.0$ ) of the 13 suture recurrences was likely to be higher than that ( $4.2 \pm 2.5$ ) of the 15 suture granulomas, but there were no significant differences ( $P = 0.29$ ) (Fig. 8).

Concerning sensitivities between DWI and FDG-PET/CT for 13 suture recurrences after surgery of lung cancer, 7 (53%) were true-positive (TP) with DWI and FDG-PET/CT, 2 (15%) were TP with FDG-PET/CT but false-negative (FN) with DWI and 4 (31%) were TP with DWI but FN with FDG-PET/CT (Table 4). The sensitivity 85% (11/13) of DWI was likely to be higher than 69% (9/13) of FDG-PET/CT for suture recurrences after surgery of lung cancer, but not significant on the McNemar test ( $P = 0.687$ ).

**Table 4**  
Comparison of sensitivities between DWI and FDG-PET/CT for 13 suture recurrences after surgery of lung cancer in the McNemar test.

		FDG-PET/CT		Total
		True-positive	False-negative	
DWI	True-positive	7	4	11
	False-negative	2	0	2
Total		9	4	13

$P = 0.453$ .

**Table 5**  
Comparison of specificities between DWI and FDG-PET/CT for 15 suture granulomas after surgery of lung cancer in the McNemar test.

		PET-CT		Total
		True-negative	False-positive	
DWI	True-negative	8	3	11
	False-positive	1	3	4
Total		9	6	15

$P = 0.625$ .

**Table 6**  
Comparison of accuracies between DWI and FDG-PET/CT for 28 suture lesions after surgery of lung cancer in the McNemar test.

		PET-CT		Total
		Correct	Incorrect	
DWI	Correct	15	7	22
	Incorrect	3	3	6
Total		18	10	28

$P = 0.343$ .

Concerning specificities between DWI and FDG-PET/CT for 15 suture granulomas, 8 (53%) were TN with DWI and FDG-PET/CT, 3 (20%) were TN with DWI but FP with FDG-PET/CT, 1 (7%) were TN with FDG-PET/CT but FP with DWI, and 3 (20%) were FP with DWI and FDG-PET/CT (Table 5). The specificity 73% (11/15) of DWI was likely to be higher than 60% (9/15) of FDG-PET/CT for suture granulomas after surgery of lung cancer, but not significant on the McNemar test ( $P = 0.625$ ).

Concerning accuracies between DWI and FDG-PET/CT for all 28 patients with the suture lesions after surgery of lung cancer, 15 (53%) were correct with DWI and FDG-PET/CT, 7 (25%) were correct with DWI but incorrect with FDG-PET/CT, 3 (11%) were correct with FDG-PET/CT but incorrect with DWI, and 3 (11%) were incorrect with DWI and FDG-PET/CT (Table 6). The accuracy 79% (22/28) of DWI was likely to be

higher than 64% (18/28) of FDG-PET/CT for the 28 suture lesions, but not significant on the McNemar test ( $P=0.343$ ).

#### 4. Discussion

Diagnosis of suture lesion after pulmonary resection for lung cancer was reported to be difficult [14]. Although much progress has been made in imaging techniques, especially in the promising field of FDG-PET/CT, these procedures should be still investigated in order to rule out suture granulomas and avoid unnecessary surgery [15]. FDG-PET/CT is the most sensitive non-invasive imaging method for the detection of tumor metastasis and recurrence, but sometimes reveals false-positive results [16]. In various organs, there were several false-positive case reports of suture granuloma by FDG-PET /CT developed at surgical margin of neoplasms in the lung [4,16–21], in the oral cavity [22], in the thyroid [23,24], and in the neck [25,26], in the stomach [27,28], in the colon [8,9,29] and in the ovary and testes [15,30]. It should be emphasized that suture granulomas can show false-positive findings on FDG-PET/CT, thus requiring differential diagnosis from recurrent tumors [26]. Surgeons must bear in mind that false-positive FDG-PET/CT results can be observed in suture granuloma [27]. In order to avoid unnecessary operations, the differential diagnosis between postoperative suture granulomas and suture recurrence is important [23].

DWI could differentiate malignancy from benignity based on diffusion. MRI could have detected recurrences of cancer in hepatocellular carcinoma [31], in lung cancer [10]. When comparing ADC values according to local recurrence, the mean ADC value for the local recurrence-free group was  $1770 \times 10^{-3} \text{ mm}^2/\text{s}^2$  (range  $1038\text{--}3105 \times 10^{-3} \text{ mm}^2/\text{s}^2$ ) versus  $981 \times 10^{-3} \text{ mm}^2/\text{s}^2$  (range  $926.6\text{--}1065 \times 10^{-3} \text{ mm}^2/\text{s}^2$ ) for the local recurrence group ( $P=0.0014$ ) [32]. In this study, diffusion detectability cores had a significant value for distinguishing suture granuloma from suture recurrence of lung cancer. Furthermore, the ADC value had a significant value for distinguishing suture granuloma from suture recurrence from lung cancer. DWI can be a valuable examination for distinguishing suture granuloma from suture recurrence after resection of lung cancer. Not only in this study but also Matsuoka et al. [6], FDG-PET/CT did not differentiate suture granuloma from suture recurrence of lung cancer. FDG-PET/CT will be thought to be a secondary recommended examination next to DWI in this situation.

In this study, patients with a suture recurrence had a tendency for a longer period of time ( $907 \pm 907$  days) after surgery than that ( $546 \pm 547$  days) of patients with a suture granuloma. 2 years and a half after surgery, a new suture lesion would be likely to be a suture recurrence rather than a suture granuloma.

MRIs have several benefits. MRI involves no contrast agents and requires less time for the examination. Furthermore, MRI has no radiation exposure and is preferable for the examinations of children who would react negatively to radiation [33]. On the other hand, there are some negative points with MRIs. An MRI examination is prohibited for people who have devices such as pacemakers or tattoos, and who suffer from claustrophobia. An MRI examination is loud which is uncomfortable for many patients.

DWI has two limitations. First, one of benign lesions which showed restricted diffusion and lower ADC values in DWI is a pulmonary abscess with histopathological necrosis. Abscesses and thrombi impede the diffusivity of water molecules because they have a hyperviscous nature [34,35]. The heavily impeded water mobility of pus may be caused by its high cellularity and viscosity, and shows the low ADC values [36]. Second, in DWI mucinous carcinomas were usually hypointense and showed higher ADC values, which could be misjudged as benign lesions in DWI [37].

This study has several limitations. This study was performed at a single institution and dealt with a small number of patients. We could not get consent forms from all the patients who developed suture lesions after pulmonary resection for lung cancer. At the result our sample size was limited. Diffusion detectability scores would be affected by respira-

tory movement, cardiac vibration and intrapulmonary air. In this study the size of suture lesions were 10 to 48 mm ( $21 \pm 11$  mm), and there was a possibility that smaller suture lesions would not be expressed accurately on the diffusion detectability score.

DWI is a non-invasive method to distinguish suture granuloma from suture recurrence after resection of lung cancer. For widespread clinical applications, DWI examinations will be most suitable to suture lesions after surgery of lung cancer for the patients who do not have devices such as pacemakers, tattoos or claustrophobia. What is possibly the largest barrier to the widespread clinical application is lack of knowledge on the part of doctors on how useful DWI is.

Further research with a larger sample size will be necessary for the conclusion of the differential efficacy of DWI in diagnosing new suture lesions after surgery of malignant tumors. Also, with a larger sample size the comparison of the differential diagnosis for new suture lesions after surgery of lung cancers between DWI and FDG-PET/CT will be necessary, because due to the small sample size, there were not significant differences of sensitivities, specificities or accuracies between DWI and FDG-PET/CT for suture lesions after surgery of lung cancers. We believe that further research into the potential of DWI may result in a new powerful examination tool for the differentiation of new suture lesions after surgery of malignant tumors.

#### 5. Conclusions

Additional DWI examination will be recommended to avoid unnecessary operations for new suture lesions after resection of malignant diseases. In these cases DWI showed to be more useful than FDG-PET / CT for the differentiation between suture recurrence and suture granuloma after pulmonary resection for lung cancer.

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#### Author contribution statement

Katsuo Usuda: Conceptualization; Data curation; Writing-original draft preparation; Writing-review and editing, Shun Iwai: Resources., Aika Yamagata: Resources, Yoshihito Iijima: Data curation, Nozomu Motono: Data curation, Munetaka Matoba: Methodology, Mariko Doai: Methodology, Sohsuke Yamada: Formal analysis, Yoshimichi Ueda: Investigation, Keiya Hirata: Methodology and software, Hidetaka Uramoto: Conceptualization; Supervision.

#### Declaration of Competing Interest

All authors have no conflict of interest to declare.

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#### References

- [1] J. Yoshida, G. Ishii, T. Yokose, K. Aokage, T. Hishida, M. Nishimura, T. Onuki, M. Noguchi, K. Nagai, Possible delayed cut-end recurrence after limited resection for ground-glass opacity adenocarcinoma, intraoperatively diagnosed as noguchi type B, in three patients, *J Thorac. Oncol.* 5 (4) (2010) 546–550.
- [2] M. Nakao, J. Yoshida, K. Goto, G. Ishii, A. Kawase, K. Aokage, T. Hishida, M. Nishimura, K. Nagai, M. Nakao, et al., Long-term outcomes of 50 cases of limited-resection trial for pulmonary ground-glass opacity nodules, *J. Thorac. Oncol.* 7 (10) (2012) 1563–1566, doi:10.1097/JTO.0b013e3182641b5c.

- [3] P.B. Shyn, R. Madan, C. Wu, S.M. Erturk, S.G. Silverman, PET/CT pattern analysis for surgical staple line recurrence in patients with colorectal cancer, *AJR Am. J. Roentgenol.* 194 (2) (2010) 414–421, doi:10.2214/AJR.09.2892.
- [4] G. Fink, P. Herskovitz, M. Nili, H. Hadar, A. Rothen, S.A. Spitzer, Suture granuloma simulating lung neoplasm occurring after segmentectomy, *Thorax* 48 (4) (1993) 405–406.
- [5] N. Takeshita, T. Tohma, H. Miyauchi, K. Suzuki, T. Nishimori, G. Ohira, K. Narushima, S. Imanishi, T. Toyozumi, H. Matsubara, Suture granuloma with false-positive findings on FDG-PET/CT resected via laparoscopic surgery, *Int. Surg.* 100 (4) (2015) 604–607, doi:10.9738/INTSURG-D-14-00140.1.
- [6] K. Matsuoka, T. Yamada, T. Matsuoka, S. Nagai, M. Ueda, Y. Miyamoto, K. Matsuoka, et al., Nodule around the staple line after pulmonary resection: benign granuloma or cancer recurrence, *Indian J. Thorac. Cardiovasc. Surg.* 35 (4) (2019) 569–574, doi:10.1007/s12055-019-00824-z.
- [7] Soo Yeon Hahn, Eun Sook Ko, Boo-Kyung Han, Yaeji Lim, Seonhye Gu, Eun Young Ko, Analysis of factors influencing the degree of detectability on diffusion-weighted MRI and diffusion background signals in patients with invasive breast cancer, *Medicine (Baltimore)* 95 (27) (2016) e4086, doi:10.1097/MD.0000000000004086.
- [8] S. Matsuura, K. Sasaki, H. Kawasaki, H. Abe, H. Nagai, F. Yoshimi, Silk Suture granuloma with false-positive findings on PET/CT accompanied by peritoneal metastasis after colon cancer surgery, *Int. J. Surg. Case.* 28 (2016) 22–25, doi:10.1016/j.ijscr.2016.09.002.
- [9] J.W. Lim, C.L. Tang, G.H. Keng, J.W. Lim, et al., False positive F-18 fluorodeoxyglucose combined PET/CT scans from suture granuloma and chronic inflammation: report of two cases and review of literature, *Ann. Acad. Med. Singapore* 34 (7) (2005) 457–460.
- [10] K. Usuda, M. Sagawa, N. Motono, M. Ueno, M. Tanaka, Y. Machida, S. Maeda, M. Matoba, Y. Kuginuki, M. Taniguchi, H. Tonami, Y. Ueda, T. Sakuma, Recurrence and metastasis of lung cancer demonstrate decreased diffusion on diffusion-weighted magnetic resonance imaging, *Asian Pac. J. Cancer Prev.* 15 (16) (2014) 6843–6848.
- [11] D. Le Bihan, E. Breton, D. Lallemand, M.L. Aubin, J. Vignaud, M. Laval-Jeantet, Separation of diffusion and perfusion in intravoxel incoherent motion MR imaging, *Radiology* 168 (2) (1988) 497–505.
- [12] A. Szafer, J. Zhong, J.C. Gore, Theoretical model for water diffusion in tissues, *Magn. Reson. Med.* 33 (5) (1995) 697–712.
- [13] F.P. Fliedner, T.B. Engel, H.H. El-Ali, A.E. Hansen, A. Kjaer, Diffusion weighted magnetic resonance imaging (DW-MRI) as a non-invasive, tissue cellularity marker to monitor cancer treatment response, *BMC Cancer* 20 (1) (2020) 134, doi:10.1186/s12885-020-6617-x.
- [14] Y. Mizukami, Y. Takahashi, Adachi H. pulmonary staple-stump granuloma after segmentectomy: two case reports and comparison with cases of stump recurrence, *Am. J. Case Rep.* 20 (2019) 1049–1056, doi:10.12659/AJCR.916906.
- [15] Ludovica Imperiale, Claudia Marchetti, Laura Salerno, Roberta Iadarola, Carlotta Bracchi, Laura Vertechy, Lucia di Francesco, Angela Musella, Elisa Bevilacqua, Primo Pennesi, Innocenza Palaia, Pierluigi Benedetti Panici, Nonabsorbable suture granuloma mimicking ovarian cancer recurrence at combined positron emission tomography/computed tomography evaluation: a case report, *J. Med. Case Rep.* 8 (2014) 202.
- [16] M. Okazaki, Y. Sano, Y. Mori, N. Sakao, S. Yukumi, H. Shigematsu, H. Izutani, Two cases of granuloma mimicking local recurrence after pulmonary segmentectomy, *J. Cardiothorac. Surg.* 15 (1) (2020) 7, doi:10.1186/s13019-020-1055-z.
- [17] M. Yüksel, A.G. Akgül, S. Evman, H.F. Batirel, Suture and stapler granulomas: a word of caution, *Eur. J. Cardiothorac. Surg.* 31 (3) (2007) 563–565.
- [18] T. Iwasaki, K. Nakagawa, H. Katsura, S. Nakane, K. Kawahara, H. Fukuda, Pulmonary suture abscess with false-positive 18F-fluorodeoxyglucose positron emission scan mimicking lung cancer recurrence, *Jpn. J. Thorac. Cardiovasc. Surg.* 54 (8) (2006) 351–355.
- [19] M. Yüksel, A.G. Akgül, S. Evman, H.F. Batirel, Suture and stapler granulomas: a word of caution, *Eur. J. Cardiothorac. Surg.* 31 (3) (2007) 563–565.
- [20] A. Ozturk, Z. Aktas, A. Yilmaz, P. Tari, F. Demirag, An amazing cause of false PET positivity: diagnosed after a lung cancer surgery, *Diagn. Cytopathol.* 45 (12) (2017) 1122–1124.
- [21] M. Tomita, Y. Matsuzaki, M. Edagawa, T. Shimizu, M. Hara, T. Onitsuka, M. Tomita, Pulmonary granuloma possibly caused by staples after video-assisted thoracoscopic surgery, *Ann. Thorac. Cardiovasc. Surg.* 9 (2) (2003) 123–125.
- [22] Y. Yoshioka, H. Nakatao, T. Hamana, A. Hamada, T. Kanda, K. Koizumi, S. Toratani, T. Okamoto, Suture granulomas developing after the treatment of oral squamous cell carcinoma, *Int. J. Surg. Case Rep.* 50 (2018) 68–71, doi:10.1016/j.ijscr.2018.07.021.
- [23] Yong Eun Chung, Eun-Kyung Kim, Min Jung Kim, Mijin Yun, Soon Won Hong, Suture granuloma mimicking recurrent thyroid carcinoma on ultrasonography, *Yonsei Med. J.* 47 (5) (2006) 748–751.
- [24] G.B. Cansu, B. Taskiran, T. Bakar, B.P. Cengiz, G.B. Cansu, et al., An unusual case in endocrinology practice: suture granuloma, *Endocr Regul.* 50 (3) (2016) 145–147, doi:10.1515/enr-2016-0016.
- [25] H. Aga, M. Hirokawa, A. Suzuki, H. Ota, M. Oshita, T. Kudo, M. Fukushima, K. Kobayashi, A. Miyauchi, Sonographic evaluation of nodules newly detected in the neck after thyroidectomy: suture granuloma versus recurrent carcinoma, *Ultrasound Int. Open.* 4 (4) (2018) E124–E130, doi:10.1055/a-0749-8688.
- [26] M. Kikuchi, Y. Nakamoto, S. Shinohara, K. Fujiwara, Y. Tona, H. Yamazaki, Kanazawa, Kurihara Y Risa, Y. Imai, Y. Naito, Suture granuloma showing false-positive finding on PET/CT after head and neck cancer surgery, *Auris. Nasus. Larynx* 39 (1) (2012) 94–97.
- [27] E. Tsujita, Y. Ikeda, N. Kinjo, Y. Yamashita, R. Kumagai, K. Taguchi, S. Yamaguchi, K. Minami, M. Yamamoto, M. Morita, Y. Toh, T. Okamura, Suture granuloma with false-positive finding on PET/CT after gastrectomy for gastric cancer, *Asian J. Endosc. Surg.* 8 (4) (2015) 457–460.
- [28] Santosh Kumar Singh, Narayan Kannan, Rajnish Talwar, Arvind Kumar Tyagi, Renu Madan, Pradeep Jaiswal, Adarsh Kumar, Suture granuloma: a rare differential diagnosis of residual/recurrent gastrointestinal stromal tumor of stomach, *Int. Cancer Conf. J.* 5 (1) (2015) 5–8.
- [29] A. Martínez-Martínez, J. García-Espinosa, A. Martínez-Martínez, Non-absorbable suture granuloma mimicking a retroperitoneal metastatic implant in a patient with sigmoid neoplasm, *Rev. Esp. Enferm. Dig.* 108 (9) (2016) 579–580.
- [30] K. Takahara, H. Kakinoki, S. Ikoma, K. Udo, S. Tobu, Y. Satoh, Y. Tokuda, M. Noguchi, S. Aoki, J. Uozumi, Suture granuloma showing false-positive findings on FDG-PET, *Case Rep. Urol.* 2013 (2013) 472642, doi:10.1155/2013/472642.
- [31] C.H. Lee, L.M. Brubaker, D.A. Gerber, Y.M. Ku, Y.H. Kim, S.S. Shin, R.C. Semelka, MRI findings of recurrent hepatocellular carcinoma after liver transplantation: preliminary results, *J. Magn. Reson. Imaging* 33 (6) (2011) 1399–1405, doi:10.1002/jmri.22326.
- [32] P. Munoz-Schuffenegger, S. Kandel, Z. Alibhai, A. Hope, A. Bezjak, A. Sun, A. Simeonov, B.C.J. Cho, M. Giuliani, A prospective study of magnetic resonance imaging assessment of post-radiation changes following stereotactic body radiation therapy for non-small cell lung cancer, *Clin. Oncol. (R Coll Radiol)* 31 (10) (2019) 720–727, doi:10.1016/j.clon.2019.05.014.
- [33] K. Darge, D. Jaramillo, M.J. Siegel, Whole-body MRI in children: current status and future applications, *Eur. J. Radiol.* 68 (2) (2008) 289–298.
- [34] T.C. Kwee, T. Takahara, R. Ochiai, D.M. Koh, Y. Ohno, K. Nakanishi, T. Niwa, T.L. Chenevert, P.R. Luijten, A. Alavi, Complementary roles of whole-body diffusion-weighted MRI and <sup>18</sup>F-FDG PET. The state of the art and potential application, *J. Nucl. Med.* 51 (10) (2010) 1549–1558.
- [35] B. Desprechins, T. Stadnik, G. Koerts, W. Shabana, C. Breucq, M. Osteaux, Use of diffusion-weighted MR imaging in differential diagnosis between intracerebral necrotic tumors and cerebral abscesses, *Am. J. Neuroradiol.* 20 (7) (1999) 1252–1257.
- [36] T. Ebisu, C. Tanaka, M. Umeda, M. Kitamura, S. Naruse, T. Higuchi, S. Ueda, H. Sato, Discrimination of brain abscess from necrotic or cystic tumors by diffusion-weighted echo planar imaging, *Magn. Reson. Imaging.* 14 (9) (1996) 1113–1116.
- [37] K. Usuda, M. Sagawa, N. Motono, M. Ueno, M. Tanaka, Y. Machida, S. Maeda, M. Matoba, Y. Kuginuki, M. Taniguchi, H. Tonami, Y. Ueda, T. Sakuma, Diagnostic performance of diffusion weighted imaging of malignant and benign pulmonary nodules and masses: comparison with positron emission tomography, *Asian Pac. J. Cancer Prev.* 15 (11) (2014) 4629–4635, doi:10.7314/apjcp.2014.15.11.4629.