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## **Radiological assessment after stereotactic body radiation of lung tumours**

### *Évaluation radiologique après la radiothérapie stéréotaxique des tumeurs pulmonaires*

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#### **Abstract**

The increasing use of stereotactic body radiation therapy for lung tumours comes along with new post-therapeutic imaging findings that should be known by physicians involved in patient follow-up. Radiation-induced lung injury is much more frequent than after conventional radiation therapy, it can also be delayed and has a different radiological presentation. Radiation-induced lung injury after stereotactic body radiation therapy involves the lung parenchyma surrounding the target tumour and appears as a dynamic process continuing for years after completion of the treatment. Thus, the radiological pattern and the severity of radiation-induced lung injury are prone to changes during follow-up, which can make it difficult to differentiate from local recurrence. Contrary to radiation-induced lung injury, local recurrence after stereotactic body radiation therapy is rare. Other complications mainly depend on tumour location and include airway complications, rib fractures and organizing pneumonia. The aim of this article is to provide a wide overview of radiological changes occurring after SBRT for lung tumours. Awareness of changes following stereotactic body radiation therapy should help avoiding unnecessary interventions for pseudo tumoral presentations.

#### **Keywords**

Radiosurgery; Lung neoplasms; Multidetector computed tomography; Positron emission tomography computed tomography

## Résumé

L'utilisation plus fréquente de l'irradiation stéréotaxique pour le traitement des tumeurs pulmonaires s'accompagne de nouveaux aspects en imagerie qui devraient être connus des médecins impliqués dans le suivi de ces patients. La pneumopathie radique y est plus fréquente qu'après une radiothérapie classique, elle peut également être plus tardive et s'associe à une présentation radiologique différente. La pneumopathie radique après une radiothérapie en conditions stéréotaxiques est localisée au parenchyme entourant la tumeur traitée et se présente comme un processus dynamique pouvant se modifier jusqu'à plusieurs années après la fin du traitement. Ainsi, l'aspect radiologique et la sévérité de la pneumopathie radique ont tendance à se modifier au cours du suivi, ce qui rend difficile le diagnostic différentiel avec une récurrence locale. Contrairement à la pneumopathie radique, la récurrence locale est rare après la radiothérapie en conditions stéréotaxiques. Les autres complications dépendent principalement de la localisation de la tumeur et incluent les atteintes des voies aériennes, les fractures costales et la pneumopathie organisée. L'objectif de cet article est de présenter une large revue des modifications radiologiques après la radiothérapie en conditions stéréotaxiques des tumeurs pulmonaires. La connaissance des aspects post-thérapeutiques peut permettre d'éviter des examens ou des interventions inutiles en présentation pseudo tumorale.

## Mots clé

Radiochirurgie ; Néoplasies pulmonaires ; scanographie multidétecteurs ; tomographie par émission de positron couplée à la tomodensitométrie

## 1. Introduction

Technological advances in image guidance and treatment planning have made it possible to develop stereotactic body radiation therapy, which consists of delivering a very high radiation dose to the target tumour while restricting the inclusion of normal tissues [1].

Stereotactic body radiation therapy has gradually become a standard treatment for patients with early stage non-small cell lung cancer non eligible for surgical treatment or oligometastatic status. Studies have shown that stereotactic body radiation therapy allows 3-year local control rates higher than 90% for early stage non-small cell lung cancer and ranging from 60 % to 91% for lung metastases [2–7]. Additionally, a pooled analysis of two randomized trials has shown that stereotactic body radiation therapy could be an option for treating operable stage I non-small cell lung cancer [4].

The increased use of stereotactic body radiation therapy for lung tumours comes along with new post-therapeutic imaging features that should be known by physicians involved in patient follow-up. The main difference between stereotactic body radiation therapy and conventionally fractionated radiotherapy relates to radiation-induced lung injury that is much more frequent in the former case,

can be delayed and has a different radiological presentation. Post-treatment changes may wrongly be attributed to local recurrence.

Therefore, the aim of this article is to provide a wide overview of radiological changes occurring after stereotactic body radiation therapy for lung tumours.

## **2. Radiation-induced lung injury**

Radiation-induced lung injury is related to an oxidative damage caused by the formation of free radicals. The early stage is characterized by an exudative phase with damages of the alveolar epithelial and vascular endothelial cells causing the release of inflammatory mediators [8,9]. This phase is followed by an organizing phase with an accumulation of blood exudate and inflammatory cells at the site of tissue injury. If the exacerbated inflammatory response persists, it leads to lung tissue damage with progressive development of fibrosis at the late stage.

Risk factors for radiation-induced lung injury include a higher radiation dose, higher proportion of tissues submitted to a high radiation dose, and a small number of fractions [9]. This explains the higher proportion of radiation-induced lung injury after stereotactic body radiation therapy as compared to conventional radiotherapy. Indeed, the concept of stereotactic body radiation therapy is to safely deliver a high dose with a hypofractionated schedule to a small radiation field, minimizing the exposition of normal tissue.

Radiation-induced lung injury is usually divided in two stages: an early stage, up to the 6<sup>th</sup> month after treatment also named transient radiation pneumonitis and a late stage also named as chronic radiation fibrosis [9].

In the context of conventional radiotherapy, transient radiation pneumonitis usually occurs within the first 3 months after the completion of treatment. If inflammation persists beyond the 6<sup>th</sup> month, fibrotic remodelling occurs to form chronic radiation fibrosis. Lesions are usually considered to be stable after the 24<sup>th</sup> month and associate architectural distortion, volume loss and presence of traction bronchiectasis. It is noteworthy that most transient radiation pneumonitis resolve without any sequelae whereas chronic radiation fibrosis is not always preceded by a transient radiation pneumonitis phase.

Conversely to conventional radiotherapy, radiation-induced lung injury occurs in most patients after stereotactic body radiation therapy. Because of the small size of the radiation field, radiation-induced lung injury remains localized to the close surrounding of the tumour and is usually asymptomatic. Indeed, only 9% of acute stereotactic body radiation therapy-related radiation-induced lung injuries are symptomatic [10], compared to 13 to 37% after conventional conformational radiotherapy. In both situations, symptoms may include dyspnoea, cough, fever and pleuritis.

Differential diagnosis with chronic obstructive pulmonary disease exacerbation can be clinically difficult. A good response to steroid therapy is observed in about 80% of cases. Risk factors for symptomatic stereotactic body radiation therapy-related radiation-induced lung injury are older age, larger tumour size and more advanced stage (IB versus IA non-small cell lung cancer) [10]. In a pooled analysis of 88 studies, Zhao et al. found no significant correlation between dosimetric factors and the rate of symptomatic forms [10]. On the other hand, Okubo et al. reported that subclinical interstitial lung disease was a risk factor for symptomatic radiation pneumonitis [11].

The median time interval from the completion of stereotactic body radiation therapy to the occurrence of radiation-induced lung injury is approximately 17 weeks, but in 25% of cases, the first radiation-induced lung changes occur more than 1 year after stereotactic body radiation therapy [12]. This time interval is longer than that for conventional radiation therapy in which changes usually appear within 4 weeks [13].

At the early stage after stereotactic body radiation therapy, there is no evidence of increased density in the lung parenchyma surrounding the treated lesion in about 21% to 46% of patients [14]. This include cases where tumour is stable, regressive or resolving, or cases with fibrosis in the position of the original tumour, not larger than the original tumour. In the other patients, stereotactic body radiation therapy-induced lung changes are usually categorized in four general patterns (**Figure 1**) that have been defined as follows by Palma et al. [15]:

- diffuse consolidation corresponding to a consolidation larger than 5 cm in largest dimension and being more extended than the aerated lung in the involved region; this pattern is found in 14% to 38% of patients [14];
- patchy consolidation corresponding to a consolidation measuring less than 5 cm in largest dimension and/or being less extensive than the aerated lung in the involved region; this pattern is found in 8% to 33% of patients [14];
- diffuse ground glass opacity corresponding to ground glass opacity larger than 5 cm, without consolidation. The involved region contains more ground glass opacity than normal lung. This pattern is found in 4% to 12% of patients [14];
- patchy ground glass opacity corresponding to a ground glass opacity area measuring less than 5 cm, without consolidation, and/or involved region containing less ground glass opacity than normal lung; this pattern is also found in 4% to 12% of patients [14].

At the late stage, after 6 month from completion of stereotactic body radiation therapy, only 1 to 20% of patients do not present radiation fibrosis [12,14]. In the other patients, three patterns are used to describe radiation pneumonitis [16] (**Figure 2**):

- modified conventional pattern is the most frequently encountered pattern (46% to 71% of patients [14]). It corresponds to a consolidation associated with volume loss and bronchiectasis. Its presentation is close to that observed in conventional radiation fibrosis but is less extensive. Consolidation may be more extensive than the initial tumour and may be associated with ground glass opacity;
- scar-like fibrosis patterns is found in 11% to 22% of patients [14]. CT images show linear opacities in the region of the treated tumour, associated with volume loss;
- mass-like fibrosis pattern presents as a focal consolidation larger than the treated tumour. This confounding aspect is found in 7% to 20% of patients and the main differential diagnosis is local recurrence [14]. The frequency of this pattern explains the difficulty of radiological follow-up of patients treated with stereotactic body irradiation.

Interestingly, Dahele et al. demonstrated that post-stereotactic body radiation therapy radiation fibrosis is a dynamic process continuing for years and that its pattern and severity are prone to changes during follow-up (**Figure 3**) [12]. In their cohort of 61 patients, the incidence of radiation fibrosis at 6, 12, 24, and 36 months was 56%, 73%, 87%, and 99%, respectively. Therefore, the first CT changes developed more than 1 year after treatment in 27% of cases. They also showed that the proportion of mass-like pattern tends to increase up to 2 years after stereotactic body radiation therapy whereas the proportions of patients with no radiation fibrosis or a modified conventional pattern decrease over time. Similarly, the maximum severity of the radiation fibrosis was usually observed around 2 years from completion of stereotactic body radiation therapy and then decreased in intensity. In 47% of cases, the morphology or severity of the radiation fibrosis continued to evolve more than 2 years after stereotactic body radiation therapy. This dynamic process of the radiation fibrosis makes it difficult to distinguish post-stereotactic body radiation therapy changes from tumour recurrence.

### **3. Tumour recurrence**

Stereotactic body radiation therapy has been reported to have an efficacy comparable to that of surgery for the treatment of early stage non-small cell lung cancer [17,4]. Recurrences are usually classified as local when occurring at the site or adjacent to the treated tumour, regional when occurring in a regional lymph node (ipsilateral hilar or mediastinal lymph lymphadenopathy), or distant when occurring at any other site. In a cohort of 676 patients with stage I–II non-small cell lung cancer treated with stereotactic body irradiation, Senthil et al. reported 5-year local and regional control rates of 90% and 87%, respectively [2]. In their study, most recurrences occurred distantly. The 5-year distant control rate was 80%. These rates are close to those observed after surgery [17,18]. Median time to local recurrence was 13 months but local recurrence occurred up to 5 years following the treatment. Thus, local recurrence is uncommon after stereotactic body radiation therapy whereas

radiation-induced lung injury is common, but there is an overlap between the median time to local recurrences and the peak of radiation-induced lung injury.

In non-small cell lung cancer, risk factors for local recurrence include larger size, squamous cell histology, low biologically effective dose and altered stereotactic body radiation therapy dose schedule [13,19,20]. In patients treated for lung metastasis, risk factors for progression are larger size, more than three lung metastases and presence extrathoracic metastases at the time of stereotactic body radiation therapy [21].

While regional and distant recurrence are usually not difficult to diagnose, diagnosing local recurrence is challenging due to the overlap of the radiological appearance with that of radiation-induced lung injury (**Figures 4 and 5**). However, distinguishing between the two entities is of great importance in patients who may be amenable to salvage therapy.

#### **4. The challenge of post-stereotactic body radiation therapy follow-up**

As it is the case after targeted therapies or radiofrequency ablation, the use of response evaluation criteria in solid tumors (RECIST) for post-stereotactic body radiation therapy follow-up suffers from several limitations [22,23]. Indeed, local response may be difficult to assess because size increase is not necessarily associated with local recurrence. In a cohort of 22 patients, Mattonen et al. reported a RECIST overall accuracy of 52% for predicting tumour recurrence at 2 to 5 months post-stereotactic body radiation therapy with a false positive rate of 72.7% and a false negative rate of 25% [24]. Thus, new criteria are required to more accurately evaluate tumour response.

A list of high-risk features has been proposed for the detection of local recurrence on CT imaging. This list was initially created based on a systematic review of the literature and then validated and further enriched in a cohort of 36 patients [14,25]. The high-risk features include:

- enlarging opacity;
- enlargement observed after 12 months;
- continuous enlargement on consecutive CT scans;
- craniocaudal growth of at least 5mm or 20%;
- bulging margin;
- linear margin disappearance;
- and disappearance of air bronchogram.

Huang et al. showed that all these features were significantly associated with local recurrence ( $p < 0.01$ ), and that the odds of recurrence increased 4-fold for each additional detected high-risk feature [25]. They also found that the presence of at least three high-risk features had a sensitivity and specificity superior to 90% for recurrence. In another series of 39 patients, Peulen et al. found that a

cut-off value of at least four high-risk features gave the best result with a sensitivity of 92% and a specificity of 85% [26]. They also reported that the occurrence of an isolated pleural effusion without any additional high-risk feature should not be considered as a sign of recurrence.

The role of positron emission tomography-CT (PET-CT) to differentiate between radiation-induced lung injury and local recurrence has also been evaluated. PET-CT response following stereotactic body radiation therapy may differ from response after conventional radiotherapy where standard uptake value usually decreases and returns to background in case of successful treatment. Studies have shown that persistent increased metabolic activity on PET-CT, even 1 to 2 years after stereotactic body radiation therapy, may not always represent persisting or recurrent disease [27,28]. Increased metabolic activity, usually observed in case of local recurrence, can also be related to radiation-induced lung injury. Ishimori et al. reported that standard uptake value increased in four out of nine patients who underwent PET-CT before and after stereotactic body radiation therapy [29]. In two patients, standard uptake value increase was observed more than 3 months following stereotactic body radiation therapy. Vahdat et al. reported a mean standard uptake value of 2 (range: 1.5 to 2.8) for controlled tumours at 18 to 24 months in a series of 21 patients with stage IA non-small cell lung cancer [30], however standard uptake values over 5 were observed in patients without local recurrence [27]. Thus, PET-CT is not currently recommended as part of systematic follow-up procedure but when disease recurrence, including local recurrence is suspected.

A post-stereotactic body radiation therapy follow-up scheme combining high-risk features and PET-CT has been proposed by Huang et al. for patients who are candidates for salvage treatment [25]. Patients are categorized as having a low- (no high-risk feature), intermediate- (one or two high-risk features), or high-risk (three or more high-risk features) of recurrence depending on the number of high-risk features on follow-up CT scans. For intermediate-risk patients, a PET-CT is recommended. If maximum standard uptake value is less than 5, close CT or PET-CT should be performed and then biopsy should be considered if results are non-reassuring. In intermediate-risk patients with maximum standard uptake value greater than 5.0 or exceeding pretreatment maximum standard uptake value and in high-risk patients, additional interventions including biopsy, resection or non-surgical salvage are recommended.

Ronden et al. investigated the incidence and patterns of change of HRFs on follow-up CT-scans in a series of 88 patients (747 CTs) without local recurrence [31]. They found that a majority of patients (53% according to at least three of the five readers) without local recurrence had at least two high-risk features, while about one fourth (23% according to at least three of the five readers) had at least three high-risk features. An enlarging opacity and an enlargement after 12 months were the two most frequent high-risk features. They had both a maximum incidence of 23.4% at 3 years post-stereotactic body radiation therapy. Only two patients (2.3%) did not have an enlarging opacity on any



follow-up scan. These authors proposed to exclude an enlargement after 12 months as an independent high-risk feature. Despite the high frequency of cases with at least two and at least three high-risk features, the authors found that only six patients underwent a PET-CT for a suspected local recurrence and only one patient underwent a transthoracic biopsy. These results underline the importance of radiological expertise and suggest that the previously mentioned recommendations should probably be reconsidered.

Other approaches to differentiate between radiation-induced lung injury and local recurrence based on magnetic resonance imaging (MRI) and radiomics have been evaluated. Using diffusion-weighted MRI to assess tumour response in 15 patients with early stage non-small cell lung cancer, Shintani et al. showed that the median apparent diffusion coefficient values at 3 and 6 months after stereotactic body radiation therapy were significantly lower in patients with local recurrence whereas no significant difference was observed in the maximum standard uptake value at any time point [32]. The apparent diffusion coefficient value is a quantitative parameter reflecting water mobility in the microenvironment. In case of successful treatment, the apparent diffusion coefficient is expected to increase due to the increase in extracellular space associated with cell death. However, the authors did not observe significant differences between apparent diffusion coefficient values after 6 months (9 month and 12 months) in patients with and without local recurrence and there was an overlap between the measured values. Radiomics is a field of medical imaging aiming to extract features (e.g. image characteristics invisible to the human eye) from medical images to create image-driven biomarkers [33,34]. The objective is to select imaging features of various complexity and to combine them using machine learning methods in order to establish correlations with clinical outcomes such as the presence of local recurrence. Several studies have evaluated radiomics on PET and CT images in the context of stereotactic body radiation therapy either to predict outcome on pretreatment images [35–38] or to differentiate between radiation-induced lung injury and local recurrence [24,39]. Comparing the performance of a radiomics model to those of six physicians for detecting local recurrence, Mattonen et al. found that radiomics can detect early changes associated with local recurrence [39]. Their algorithm had a false positive and a false negative rates of 24% and 23%, respectively.

## **5. Complications after SBRT**

Stereotactic body radiation therapy is associated with a lower complication rate than that reported for conventional radiotherapy. Indeed, even though stereotactic body radiation therapy-related radiation pneumonitis and radiation fibrosis are being observed in the vast majority of patients, only a few are symptomatic and should thus be considered as true complications. Other complications include:

### ***5.1. Radiation-induced organizing pneumonia***

Organizing pneumonia can present with symptoms close to symptomatic radiation pneumonitis, including dyspnoea, cough and fever. Whereas lesions are limited to the irradiated area in radiation

pneumonitis, lung infiltrates in organizing pneumonia are observed outside the radiation field and frequently migrate (**Figure 6**). The mechanism of radiation-induced organizing pneumonia remains unknown but lymphocyte-mediated hypersensitivity reactions and induced immune disorders have been suggested [9]. In a cohort of 189 patients, Murai et al. reported an incidence of symptomatic stereotactic body radiation therapy-related organized pneumonia of 4% and 5% at 1 and 2 years after treatment, respectively [40]. Ochiai et al. reported a time interval from the completion of stereotactic body radiation therapy to the occurrence of organizing pneumonia of 6 to 18 months [41]. Symptoms and lesions can rapidly improve under steroid therapy, but up to 20% to 44% of patients relapse.

### ***5.2. Complications observed for central tumours***

Central tumours are defined as tumours located within 2 cm of any mediastinal critical structure, including the bronchial tree, oesophagus, heart, brachial plexus, major vessels, spinal cord, phrenic nerve, and recurrent laryngeal nerve [42]. Central tumours are associated to a higher risk of complications [43].

In case of central tumour abutting the trachea or a proximal bronchus, it is possible to observe at the early stage a bronchial thickening of the adjacent airway with or without stenosis [13,43]. At the late stage, a stricture can persist. This can cause obstruction or even atelectasis. More rarely, bronchial necrosis with tracheobronchial fistula may occur. Recurrent pneumonitis in patients who underwent stereotactic body radiation therapy for central lung tumour is suggestive of the diagnosis [13].

When the treated tumour is close to the oesophagus, oesophagitis, stricture, perforation, and/or tracheoesophageal fistula can be encountered [43].

Vascular complications such as aortitis or fatal haemoptysis complicating radiation-induced injury to the central pulmonary arteries are also possible but have been rarely reported [43].

### ***5.3. Complications observed for peripheral tumours***

In patients treated for subpleural tumours, rib fractures may occur (**Figure 7**). This delayed complication usually occurs 16 to 48 months after completion of stereotactic body radiation therapy with an incidence of 16 to 24%. One third of patients are symptomatic [44,45]. These patients can also present focal pleural thickening [13].

## **6. Follow-up recommendations**

The currently recommended algorithm for imaging follow-up after stereotactic body radiation therapy for non-small cell lung cancer mainly follows follow-up recommendations after lung surgery [46-48]. It includes a chest CT every 3 to 6 months during the first year, then a chest CT every 6 months for 3 years and an annual chest CT from the 4<sup>th</sup> after stereotactic body radiation therapy. Contrast medium

injection is optional the first 2 years and then unenhanced chest CT is recommended. Importantly, PET-CT is not recommended as part of the systematic follow-up.

The presence of high-risk features on CT images can help detecting local recurrence but is not specific. In the setting of suspected recurrence, discussion in a multidisciplinary team is recommended to decide on expert opinion whether closer follow-up, PET-CT or biopsy should be performed.

## **7. Conclusion**

Stereotactic body radiation therapy is an increasingly popular method for the management of primary and secondary lung tumours. Knowing specificities of radiological assessment after stereotactic body radiation therapy is important, especially being able to recognize radiation-induced lung injury as a possible aetiology of lung changes in the radiation field, even several years after the completion of treatment. Despite the published high-risk CT features and other approaches based on radiomics and lung MRI, differentiating between radiation-induced lung injury and local recurrence remains difficult. It is important to know that radiation-induced lung injury may mimic local recurrence and is more frequent than the later. Increased knowledge of post-stereotactic body radiation therapy imaging changes and multidisciplinary team discussions should help avoiding unnecessary examinations or interventions.

## **Author contributions**

Conceptualization: GC, KM, PG, MPR. Writing - original draft: GC - review and editing: KM, PG, MPR.

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## Figure legends

**Figure 1.** Radiological patterns of transient radiation pneumonitis after stereotactic body radiation therapy. a) No evidence of increasing density. b) Diffuse consolidation larger than 5 cm in largest dimension. c) Patchy consolidation. d) Diffuse ground glass opacity larger than 5 cm, without consolidation. e) Patchy ground glass opacity

**Figure 2.** Radiological patterns of radiation fibrosis after stereotactic body radiation therapy. a) No evidence of increased density. b) Modified conventional with consolidation, loss of volume and bronchiectasis. c) Scar-like fibrosis. d) Mass-like fibrosis pattern presenting as a focal consolidation larger than the treated tumour.

**Figure 3.** Changes in pattern and severity of radiation-induced lung injury after stereotactic body radiation therapy. a) Baseline chest CT shows a small nodule in the left lower lobe. b) At 6 months, no radiation pneumonitis is seen. c-g: Radiation-induced lung injury first manifests at 12 months (c), with an increasing severity from the 12<sup>th</sup> to the 36<sup>th</sup> month (d: 18 months; e: 24 months; f: 30 months; g: 36 months). On chest CT scan performed at 36 months, a mass-like fibrosis larger than the treated lesion is seen (g).

**Figure 4.** Post-stereotactic body radiation therapy radiation-induced lung injury mimicking local recurrence. a) Baseline chest CT shows a nodule in the right lower lobe. b) 6 months post-stereotactic body radiation therapy chest CT. c) 12 months post-stereotactic body radiation therapy chest CT. d) At 18 months after completion of stereotactic body radiation therapy, a mass larger than the treated lesion is seen. Therefore, a PET-CT is performed and shows only a mild (<sup>18</sup>F)-fluorodeoxyglucose uptake (maximum standard uptake value: 2). e) 19 months post stereotactic body radiation therapy chest CT. f) As the mass continued to enlarge on the chest CT performed at 24 months, the patient underwent a transthoracic biopsy that showed no tumoral cells, only inflammatory changes. g) 25 months post-stereotactic body radiation therapy chest CT.

**Figure 5.** Recurrence of a lung adenocarcinoma after stereotactic body radiation therapy. a,b) Baseline chest CT (a) and PET-CT (b) show a hypermetabolic lung nodule in the right lower lobe (maximum standard uptake value: 4). c) Follow-up chest CT performed 18 months after completion of the treatment (shows a mass-like consolidation in the radiation field. d,e) PET-CT examination shows increased fluorodeoxyglucose uptake of the lung mass (maximum standard uptake value: 7, on d) higher than that of the treated nodule on the baseline examination, as well as an area of increased metabolic activity in the liver (e). This was suggestive of local and distant recurrence.

**Figure 6.** Stereotactic body radiation therapy-induced organizing pneumonia. A 65-year-old patient with a right lower lobe adenocarcinoma treated by stereotactic body irradiation. a) baseline exam. b) Follow-up examination at 12 months after completion of stereotactic body radiation therapy showing

lung consolidations bilaterally; these consolidations were absent on the baseline CT exam (a). c) after treatment by steroids, consolidations have disappeared. Radiological presentation and evolution are suggestive of organizing pneumonia.

**Figure 7.** Stereotactic body radiation therapy-induced rib fracture. a) CT angiography in an 80-year old patient with stage I peripheral lung adenocarcinoma treated by stereotactic body irradiation. b) Twenty months after the completion of stereotactic body radiation therapy, a pulmonary CT angiography was performed for suspicion of pulmonary embolism due to chest pain. The CT angiography was negative for pulmonary embolism but showed stereotactic body radiation therapy-induced rib fractures (arrows).









































































