Research in Diagnostic and Interventional Imaging 10 (2024) 100047

Contents lists available at ScienceDirect

Research in Diagnostic and Interventional Imaging

journal homepage: https://www.journals.elsevier.com/redii

Original article

Chest tube placement incidence when using gelatin sponge torpedoes after pulmonary radiofrequency ablation

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ARTICLE INFO

Article History:
Received 28 November 2023
Accepted 1 April 2024
Available online 25 April 2024

Keywords:
Lung radiofrequency
Tract embolization
Gelatin sponge
Chest tube placement
Computed tomography
Cone beam computed tomography

ABSTRACT

Purpose: To assess the efficacy of the gelatin torpedoes embolization technique after lung neoplastic lesions percutaneous radiofrequency ablation (PRFA) to reduce chest tube placement rate and hospital length of stay, and the safety of this embolization technique.

Materials and methods: A total of 114 PRFA of lung neoplastic lesions performed in two centers between January 2017 and December 2022 were retrospectively reviewed. Two groups were compared, with 42 PRFA with gelatin torpedoes embolization technique (gelatin group) and 72 procedures without (control group). Procedures were performed by one of seven interventional radiologists using LeVeen CoAccess^{TM} probe. Multivariate analyses were performed to identify risk factors for chest tube placement and hospital length of stay.

Results: There was a significantly lower chest tube placement rate in the gelatin group compared to the control group (3 [7.1 %] vs. 27 [37.5 %], $p < 0{,}001$). Multivariate analysis showed a significant association between chest tube placement and gelatin torpedoes embolization technique (OR: 0.09; 95 % CI: 0.02–0.32; $p = 0.0006$). No significant difference was found in hospital length of stay between the two groups. Multivariate analysis did not show a significant relationship between hospital length of stay and gelatin torpedoes embolization technique. No embolic complication occurred in the gelatin group.

Conclusion: Gelatin torpedoes embolization technique after PRFA of lung neoplastic lesions resulted in significantly reduced chest tube placement rate in our patient population. No significant reduction in hospital length of stay was observed. No major complication occurred in the gelatin group.

1. Introduction

Percutaneous radiofrequency ablation (PRFA) of lung malignancy is a minimally invasive interventional technique to destroy neoplastic lung lesions [1]. Pneumothorax remains the most common complication after PRFA of neoplastic lung lesions, with an estimated incidence of 9–90 % [2–4]. Chest tube placement is required to evacuate pneumothorax in 3.3 to 58 % of procedures [4–7]. Chest tube placement secondary causes discomfort for the patient, increased duration of the procedure, increased risk of complications, prolonged hospital length of stay and costs for the health care system. Therefore, it is important to decrease chest tube placement incidence after PRFA of lung malignancies.

To reduce pneumothorax and chest tube placement incidence after computed tomography (CT) guided percutaneous lung biopsy, numerous studies have been performed to assess the efficacy of some embolization techniques, such as autologous blood patch, hydrogel plug, sodium chloride and gelatin sponge [8]. Successful results have been observed in these various studies, including Renier et al. study who demonstrated the efficacy of a tract embolization technique with gelatin sponge slurry [9].

Only few studies are available regarding tract embolization technique after PRFA of lung lesions, especially using gelatin sponge [3,10]. Since 2017, the tract embolization technique using gelatin sponge torpedoes has been used at Nantes university dospital (CHU) and Institut de cancérologie de l'Ouest (ICO) in Saint-Herblain

Abbreviations: CBCT, Cone beam computed tomography; CHU, Nantes university hospital; CI, Confidence interval; CT, Computed tomography; ICO, Institut de cancérologie de l'Ouest; IQR, Interquartile ranges; OR, Odds ratio; PRFA, Percutaneous radiofrequency ablation; SD, Standard deviations

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https://doi.org/10.1016/j.redii.2024.100047

(France). The purpose of this study was to evaluate whether tract embolization technique with gelatin sponge torpedoes could reduce the incidence of chest tube placement and the hospital length of stay after PRFA of lung lesions. Moreover, the safety of this embolization technique has also been assessed.

2. Materials and methods

2.1. Study and population

An institutional review board agreement was obtained for a retrospective review of all patient aged of eighteen years old or older who underwent PRFA of lung neoplastic lesion with a multi-tined retractable probe between January 2017 and December 2022.

Exclusion criteria were as follows: no procedure report available, no use of coaxial needle, more than two lesions treated at the same time, use of a different embolization material than gelatin torpedo, embolization of only one needle pathway when two lesions were treated simultaneously. PRFA were performed by seven interventional radiologists, whom were separated into two groups: “experienced” and “not experienced”. The experienced radiologists performed at least fifteen PRFA of lung lesions per year.

2.2. Preoperative consultation and imaging

PRFA was approved by an interdisciplinary tumor board. In order to receive information about benefits and risks of the procedure, each patient underwent a preprocedural consultation. Informed consent of the patient was required before procedure.

Preprocedural thoracic CT scan was performed within two months before PRFA. If a patient required bilateral treatment, lungs were treated separately several weeks apart to avoid major complications.

2.3. PRFA procedure

All procedures were performed under general anesthesia, which allows better control of respiratory movements. Ventilation at very high speed and very low pressure in the airways (jet ventilation) was frequently used. This ventilation technique reduces amplitude of respiratory movements and consequently facilitates the targeting of neoplastic lesion.

Patients were placed in prone, lateral or dorsal decubitus, in order to provide the shortest and safest pathway with the radiofrequency probe through lung parenchyma. Grounding pads were placed on each of the patient’s thighs. Thoracic skin entry point was prepared with antiseptic solutions and surrounded by sterile drapes.

PRFA procedures were performed under CT (Somatom Definition AS 20, Siemens, Germany) or cone beam computed tomography (CBCT) guidance (Allura Xper FD20, Philips, Netherlands). Preliminary imaging was performed in order to determine the most appropriate path up to the lesion. An attempt was made to avoid crossing a vessel, bronchus, scissure or other critical structure. If necessary, biopsies and fiducial insertion were performed under CT guidance, using a coaxial needle, always before PRFA needle placement.

A RF3000™ radiofrequency generator (Boston Scientific Corporation, USA) was used. PRFA was performed with a radiofrequency multitined retractable 15 gauge probe, and 14 gauge coaxial needle (LeVeen CoAccess™, Boston Scientific Corporation, USA).

Coaxial needle was introduced into the lung parenchyma, with regular CT or CBCT imaging to control needle placement. Once needle was properly placed, the stylet was replaced by the radiofrequency probe. Then, the array of tines was deployed and heating process was performed.

2.4. Tract embolization technique

After the heating process was completed, probe was removed from the coaxial sheath. In the control group, the coaxial sheath was removed without any embolization technique. In the gelatin group, needle path was embolized with two gelatin sponge torpedoes of 1 mm large and 10–15 mm length each (CuraSpon® Standard, CuraMedical, Assendelft, Netherlands) (Figs. 1 and 2).

Each torpedo was inserted into the coaxial sheath and pushed with 2 mL of sodium chloride, slowly, without excessive pressure. The first torpedo was placed into lung parenchyma upon contact with the treated area, where the risk of damaging a bronchus or bronchiola was highest with the heating process. The second torpedo was placed at the junction between lung parenchyma and visceral pleura (Fig. 3). The aim was to plug the entire needle path and avoid

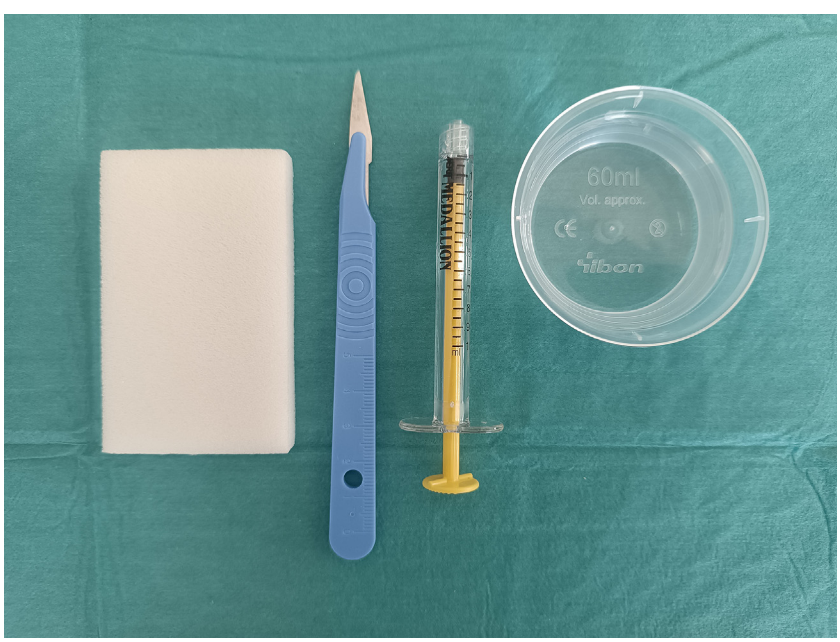

Fig. 1. Gelatin sponge embolization technique equipment: from the left to the right: gelatin sponge (CuraSpon® Standard), scalpel, syringe, cup filled with sodium chloride.

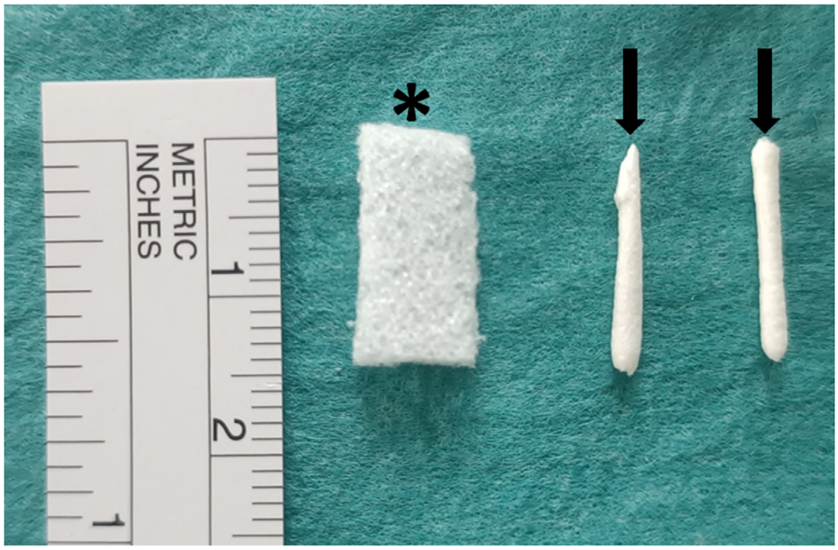

Fig. 2. Gelatin sponge torpedoes: piece of gelatin sponge before formation of the torpedo (asterisk). Two torpedoes ready to be used for embolization (arrows).

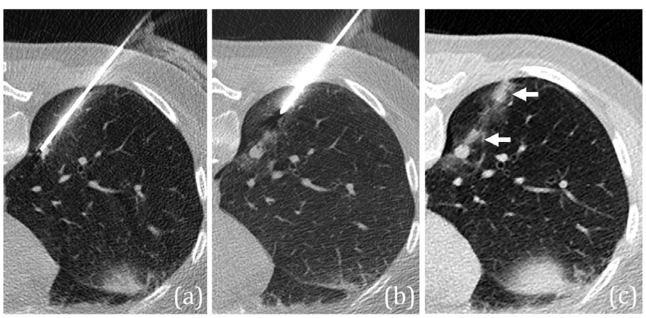

Fig. 3. Gelatin sponge embolization technique. (a) At the end of PRFA, coaxial sheath within lung parenchyma. (b) Placement of the two gelatin torpedoes within lung parenchyma while removing the coaxial sheath. (c) Two gelatin torpedoes placed along the radiofrequency probe path at the end of the procedure (arrows).

any potential risk of communication between a bronchus or bronchiola and the visceral pleura.

In the gelatin group, when two lesions were treated at the same time, torpedoes were used for both needle tracks.

2.5. Pneumothorax management

Postprocedural imaging was performed 3 to 5 min after the coaxial sheath removal to assess technical success and look for complications, including pneumothorax. Pneumothorax was defined as presence of air in the pleural space between parietal and visceral pleura. On postprocedural imaging, pneumothorax thickness was classified as mild (< 2 cm), moderate (⩾ 2 and < 4 cm), and severe (⩾ 4 cm). A pneumothorax was considered complete when the pleura was detached over its entire height.

Decision to treat pneumothorax was made jointly by radiologist and anesthesiologist. Chest tube was places in the following situations: poor clinical tolerance after needle removal, great abundance pneumothorax, and rapid increase in size of the pneumothorax.

2.6. Hospitalization

All patients were hospitalized at least until the next day after the procedure. At day 1 or earlier in case of symptoms, a chest X-ray or a CT scan was also performed to look for complications. Upon discharge, patients received explanations of symptoms that should lead to an emergency consultation.

2.7. Safety

All post-PRFA complications were recorded for three months from the day of lung PRFA. The complication that can be caused by gelatin sponge torpedoes technique have been classified in two categories: major complications and minor complications. Major complications were ischemic stroke, myocardial infarction, other peripheral ischemia, pulmonary embolism associated with signs of hemodynamic failure, and death. Minor complications included pulmonary embolism without signs of hemodynamic failure, and bacterial pneumopathy.

2.8. Statistical analysis

Quantitative variables were summarized as means and standard deviations (SD), or medians and interquartile ranges (IQR) if not normally distributed. Categorical variables were presented as effectives and percentages. Tests used to compare the distributions between the two groups were: Student's *t*-test for normally distributed continuous variable, Mann-Whitney-Wilcoxon test if not normally distributed and Fisher's exact test for categorical variables. All statistical tests were two-sided with a type 1 error set at 5 %. Multiple logistic regression analyses were performed to determine whether chest tube placement and hospital length of stay could be independently associated with gelatin embolisation technique. Known or suspected confounders were identified by the clinician group from the literature and used as covariates in the model. We computed the odds ratios (OR) with the corresponding 95 % intervals to answer the study question. Analyses were performed using Rv.4.2.2.

3. Results

3.1. Population characteristics and procedural parameters

Among 157 patients eligible for inclusion, 43 were excluded for the following reasons: five patients had no report available in their medical file, no coaxial needle was used in eight procedures, two patients had more than two lesions treated at the same time, a different embolization material was used in 27 procedures, and only one of the two PRFA paths was embolized in one procedure. Therefore, a total of 114 patients were included, with 42 patients in the gelatin

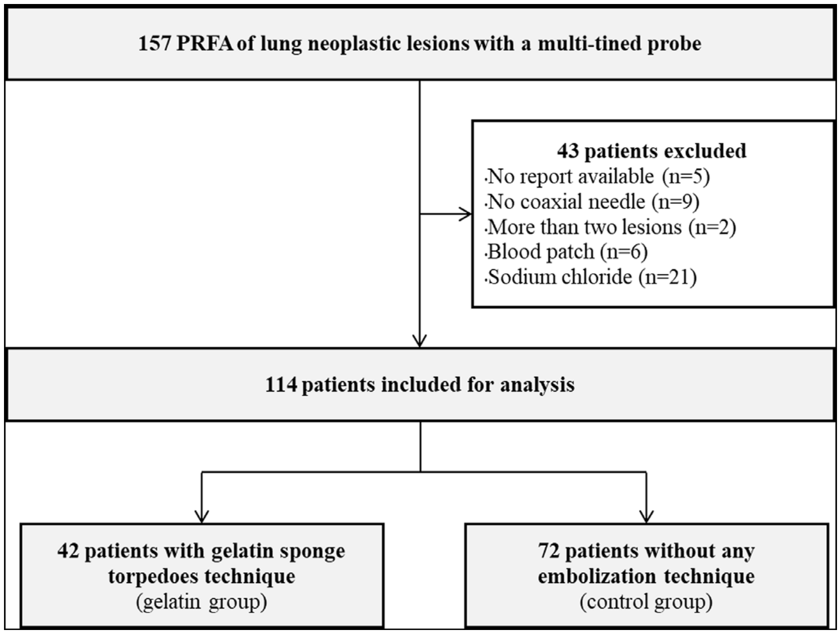

Fig. 4. Evaluation of tract embolization technique with gelatin sponge torpedoes after percutaneous radiofrequency ablation of lung lesions: flowchart of patient selection. PRFA: percutaneous radiofrequency ablation.

group and 72 patients in the control group (Fig. 4). In our study, a same patient treated twice at two different times was considered as two different patients. Moreover, radiologists using the gelatin sponge torpedoes technique have used it for almost all of their patients.

A total of 126 lesions were treated during 114 procedures, because some patients had two lesions treated during the same procedure (five patients in the gelatin group and seven patients in the control group). Therefore, a comparative analysis of patient characteristics, procedural parameters, pneumothorax management, and hospitalization was performed (Table 1), and a second comparative study of lesion characteristics and data related to lesion treatment was realized separately (Table 2).

Both groups had similar preprocedural characteristics regarding sex, age, smoking history, emphysema, homolateral chest surgery history, diffuse interstitial lung disease, homolateral radiation pneumonitis (Table 1).

Procedural parameters were similar in the two groups, with the exception of three. In the gelatin group compared to the control group, most procedures were performed in the university hospital, under CT guidance and radiologists were more experienced (Table 1).

3.2. Lesion characteristics and data related to lesion treatment

There were more primary neoplasia in the gelatin group than in the control group. In the gelatin group, lesions were larger and more frequently upon contact with bronchus . In addition, there was no trans-scissural crossing of radiofrequency probe and heating time was shorter in the gelatin group (Table 2).

3.3. Chest tube placement

Pneumothorax incidence was similar in both groups, but pneumothorax thickness was significantly lower in the gelatin group. Chest tube placement incidence was significantly lower in the gelatin group compared to the control group (Table 1). Based on multivariate logistic regression analysis, we found that the use of gelatin torpedoes embolization technique significantly reduced chest tube placement (Table 3).

3.4. Hospital length of stay

No significant difference in hospital length of stay was observed between the two groups (Table 1). Multivariate logistic regression analysis showed no statistical association between hospital length of stay and the use of gelatin sponge torpedoes technique after PRFA of lung neoplastic lesion. Hospital stay duration was significantly lower for PRFA performed in ICO compared to those performed in CHU (Table 4).

3.5. Safety

In both groups, no death occurred during procedure or within three months afterward. No case of vascular embolism secondary to the use of gelatin sponge torpedoes technique was reported. In control group, a gas embolism occurred during radiofrequency probe placement. In the gelatin group, three patients were managed for bacterial pneumonia within three months following procedure in gelatin group, and none in the control group.

In addition, in the gelatin group a hemothorax due to a pseudoaneurysm and a diaphragmatic paralysis have been recorded after procedure, and two patients required a bronchoscopic treatment to treat a bronchopleural fistula in the control group.

3.6. Others results

Only one patient in the gelatin group had a follow-up chest X-ray on day 1. All other patients in both groups had a follow-up chest CT scan on day 1.

The majority of pneumothorax occurred immediately after PRFA needle removal (25/34 vs. 43/51; $p = 0.74$). The majority of chest tubes were placed within minutes of PRFA needle removal (2/3 vs. 24/27; $p = 1$). The remaining chest tubes were inserted on day 1.

4. Discussion

In the present study, use of the gelatin sponge torpedoes technique after PRFA of lung malignancy significantly reduced chest tube

Table 1
Evaluation of tract embolization technique with gelatin sponge torpedoes after percutaneous radiofrequency ablation of lung lesions: patient, procedure parameters, pneumothorax management and hospitalization.

Variable	Gelatin group (*n* = 42)	Control group (*n* = 72)	*p*-value
Sex, n *(%)*			0.894
Male	22 (52.4 %)	40 (55.6 %)	
Female	20 (47.6 %)	32 (44.4 %)	
Age, years (± SD)	65.62 ± 12.62	67.62 ± 8.74	0.322
Smoking history, n *(%)*	21 (50.0 %)	28 (38.9 %)	0.337
Emphysema, n *(%)*	18 (42.9 %)	24 (33.3 %)	0.415
Emphysema gradation, n *(%)*			0.706
Mild	12/18 (66.7)	13 (54.2)	
Moderate	3/18 (16.7)	6 (25.0)	
Confluent	3/18 (16.7)	5 (20.8)	
Destructive	0 (0.0)	0 (0.0)	
Homolateral chest surgery, n *(%)*	5 (11.9 %)	4 (5.6 %)	0.394
Diffuse interstitial lung disease, n *(%)*	1 (2.4 %)	0 (0.0)	0.784
Homolateral radiation pneumonitis, n (%)	1 (2.4 %)	2 (2.8 %)	1
Center, n (%)			<0.001
Institut de cancérologie de l'Ouest	6 (14.3)	49 (68.1)	
CHU de Nantes	36 (85.7)	23 (31.9)	
Imaging guidance, n (%)			<0.001
CT scan	32 (76.2 %)	22 (30.6 %)	
CBCT	10 (23.8 %)	50 (69.4 %)	
Experienced radiologist	41 (97.6 %)	52 (72.2 %)	0.002
Patient position, n *(%)*			0.696
Prone position	15 (35.7 %)	23 (31.9 %)	
Lateral decubitus	1 (2.4 %)	4 (5.6 %)	
Supine position	26 (61.9 %)	45 (62.5 %)	
Jet ventilation, n *(%)*	31 (77.5 %)	48 (67.6 %)	0.375
Biopsy during procedure, n *(%)*	10 (23.8 %)	19 (26.4 %)	0.935
Fiducial during procedure, n *(%)*	2 (4.8 %)	3 (4.2 %)	1
Pneumothorax, n *(%)*	34 (80.9 %)	51 (70.8 %)	0.402
Chest tubes, n *(%)*	3 (7.1 %)	27 (37.5 %)	0.001
Pneumothorax maximum thickness, mm [IQR]	7.5 [4.00–12.75]	13.00 [6.5–22.00]	0.006
Pneumothorax grade, n *(%)*			0.028
Mild	31/34 (91.2 %)	35/51 (68.6 %)	
Moderate	3/34 (8.8 %)	9/51 (17.6 %)	
Severe	0/34 (0.0)	7/51 (13.7 %)	
Complete pneumothorax	5/34 (14.7 %)	19/51 (37.3 %)	0.05
Chest tube duration, days [IQR]	3.00 [3.00–5.50]	1.50 [1.00–2.00]	0.044
Hospital length of stay, days [IQR]	1.00 [1.00–2.00]	1.00 [1.00–2.00]	0.345
Hospital length of stay > to 24 h, n (%)	18 (42.9 %)	24 (33.8 %)	0.447
Hospitalization within 3 months following PRFA, n (%)	12 (29.3)	13 (18.3)	0.269

Distribution are summarized as mean ± SD, median [IQR] or effective (%). IQR: interquartile range; PRFA: percutaneous radiofrequency ablation.

Table 2
Evaluation of tract embolization technique with gelatin sponge torpedoes after percutaneous radiofrequency ablation of lung lesions: lesion characteristics and data related to lesion treatment.

Variable	Gelatin group (*n* = 47)	Control group (*n* = 79)	*p*-value
Laterality, n *(%)*			1
Right	26 (55.3 %)	38 (48.1 %)	
Left	21 (44.6 %)	41 (51.9 %)	
Lobe, n *(%)*			0.759
Inferior	13 (27.7 %)	25 (31.6 %)	
Middle	2 (4.3 %)	5 (6.3 %)	
Superior	32 (68.1 %)	49 (62.0 %)	
CT appearance, n *(%)*			0.179
Condensed	43 (91.5 %)	75 (94.9 %)	
Ground glass	0 (0.0)	2 (2.5 %)	
Mixed	4 (8.5 %)	2 (2.5 %)	
Lesion size, mm [IQR]	13.00 [10.00–16.50]	11.00 [9.00–14.00]	0.009
Excavation, n *(%)*	5 (10.6 %)	3 (3.8 %)	0.252
Pleura–lesion distance, mm [IQR]	16.00 [8.50–25.50]	13.00 [8.50–20.00]	0.12
Pleural contact, n *(%)*	4 (8.5 %)	7 (8.9 %)	1
Bronchial contact, n *(%)*	26 (55.3 %)	26 (32.9 %)	0.022
Primary neoplasia, n *(%)*	12 (25.5 %)	7 (8.9 %)	0.019
Secondary neoplasia, n *(%)*	31 (66 %)	67 (84.8 %)	0.019
Histology unknown, n *(%)*	4 (8.5 %)	5 (6.3 %)	0.766
Puncture site, n *(%)*			0.5
Anterior	14 (29.8 %)	30 (38.0 %)	
Lateral	19 (40.4 %)	32 (40.5 %)	
Posterior	14 (29.8 %)	17 (21.5 %)	
Puncture angle, mm [IQR]	55 [45.50–75.00]	59 [45.00–69.00]	0.839
Parenchyma needle length, mm	35.38 ± 13.88	38.82 ± 18.48	0.273
Emphysema along needle track, n *(%)*	4 (8.5 %)	7 (9.0 %)	1
Trans-scissural crossing, n *(%)*	0 (0.0)	11 (13.9 %)	0.018
Transbronchial crossing, n *(%)*	10 (21.3 %)	7 (9.0 %)	0.094
Treatment area diameter, n *(%)*			0.5
3 cm	29 (61.7 %)	56 (70.9 %)	
3.5 cm	8 (17.0 %)	12 (15.2 %)	
4 cm	10 (21.3 %)	11 (13.9 %)	
Standard protocol, n *(%)*	41 (93.2 %)	66 (83.5 %)	0.214
Maximum power, W [IQR]	70.00 [52.50–97.50]	70.00 [40.00–90.00]	0.281
Heating time, min [IQR]	12.00 [10.00–14.50]	15.00 [11.00–21.00]	0.013

Distribution are summarized as mean ± SD, median [IQR] or effective (%). IQR: interquartile range.

Table 3
Evaluation of tract embolization technique with gelatin sponge torpedoes after percutaneous radiofrequency ablation of lung lesions: multivariate logistic regression analysis of chest tube placement.

Variable	Odds ratio	95 % confidence interval	*p*-value
Gelatin sealing	0.09	0.02–0.32	0.0006
Number of lesion treated	1.90	0.41–8.22	0.39264
Emphysema	1.94	0.69–5.59	0.20842
Bronchial contact	1.41	0.51–3.93	0.50175
Homolateral chest surgery	0.31	0.01–2.30	0.32585
Experienced radiologist	1.89	0.61–6.52	0.28372

Table 4
Multivariate logistic regression analysis of hospital length of stay.

Variable	Odds ratio	95 % confidence interval	*p*-value
Gelatin sealing	0.73	0.27–1.87	0.5157
Age	0.99	0.95–1.03	0.6654
Emphysema	1.24	0.53–2.88	0.6156
Center (ICO)	0.28	0.10–0.70	0.0084

placement rate. No significant reduction in hospital length of stay was observed. No major complication occurred in the gelatin group.

In 1996, the first PRFA of lung neoplastic lesion was performed in humans [1]. Since then, this technique has shown effective results, including local control for lesions less than three centimeters, overall survival and progression-free survival similar to thoracic surgery [5,11–14]. Pneumothorax is the most common complication after PRFA of lung lesion, with an estimated incidence between 9 and 90 % [2–4]. Some risk factors for pneumothorax after PRFA are well described, such as emphysema, number of lesions treated at the same time, no previous history of thoracic surgery, length of aerated lung parenchyma crossed by PRFA probe, treated area size, and procedure duration [4,15,16]. Pneumothorax incidence differs between studies, probably due to population heterogeneity among studied populations [3,17,18].

After PRFA of lung neoplastic lesion, pneumothorax mechanism is complex and not yet fully understood. Its mechanism presents notable differences from lung biopsy one. Radiofrequency probe realizes a larger pleural breach (14−15 gauge) than lung biopsy needle (18−20 gauge). PRFA also involves a heating process, resulting in necrosis and vessels occlusion in the treated area secondary to aggression of the lung parenchyma [19]. Experiments in a porcine model using LeVeen CoAccess^{TM} probe revealed histological changes along coaxial needle path, with protein alteration of pneumocytes [20]. The insulating effect of lung tissue concentrates heat within the treated lesion ("oven effect"), therefore heat can diffuse along coaxial needle, alter lung tissue, and consequently favored pneumothorax development [13,21,22].

Large pneumothorax can compress mediastinum, impair systemic venous return, decrease cardiac output, and ultimately result in death if not drained. When respiratory symptoms appear or pneumothorax is important, it is necessary to remove air from pleural space either by aspiration or chest tube placement. Chest tube placement carries its own additional iatrogenic complications (infection, bleeding, pain, prolonged hospital length of stay, etc.). Therefore, it is necessary to reduce incidence and abundance of pneumothorax after PRFA of lung neoplastic lesions.

In the literature, chest tube placement incidence after pulmonary PRFA ranges between 3.3 and 58 % [4,5,7,23]. MacDuff et al. suggested that clinical evaluation is probably more important than pneumothorax size to determine management strategy [24]. Indeed, the same pneumothorax will not have the same consequences on patients without any comorbidity and patients with chronic obstructive pulmonary disease, pulmonary fibrosis or other respiratory comorbidities. In our study, decision to treat pneumothorax was made jointly by radiologist and anesthesiologist according to poor clinical tolerance after needle removal, great abundance and rapid increase in size of pneumothorax.

To decrease pneumothorax and chest tube placement incidence after CT guided lung biopsy, some embolization techniques such as autologous blood patch, hydrogel plug, sodium chloride and gelatin sponge have been evaluated [8]. However, those embolization techniques may not be as effective in PRFA of lung lesions due to the many differences with the lung biopsy procedure. Adjusted embolization techniques to PRFA should be evaluated.

Gelatin sponges are readily available, inexpensive and commonly used in routine practice by interventional radiologists during vascular embolization procedures. For these reasons, some centers have evaluated the gelatin sponge embolization technique during PRFA of lung lesion to reduce pneumothorax and chest tube placement rates.

Izaaryerne et al. conducted a prospective, single-center, randomized study comparing tract embolization of radiofrequency pathway with three contrast iodine-soaked gelatin torpedoes versus no embolization technique [3]. Dassa et al. performed a retrospective, single-center study comparing tract embolization of radiofrequency pathway with a gelatinous sponge slurry with iodinated contrast versus no embolization technique [10]. Both studies showed a significant decrease of pneumothorax and chest tube placement rates with using gelatin sponge embolization technique. In addition, Dassa et al. found a significant decrease in the hospital length of stay in their gelatin group. These authors used iodinated contrast medium to facilitate visualization of gelatin sponge, however contrast medium added cost to the procedure. In our study torpedoes are visible on the immediate CT scan in most cases without using ionated contrast medium. Moreover in our study, there was no statisctically significant difference between the two groups in the incidence of pneumothorax, although pneumothorax was thinner in the gelatin group compared with the control group.

There is no established standard for hospital length of stay after PRFA of lung lesion.

Usually, minimum hospital length of stay is 24 h after procedure [25,26]. Furthermore, if a pneumothorax requiring chest tube placement appears, chest tube must be left for at least 24 h [27].

Our study did not show a significant decrease in the hospital length of stay in the gelatin groups. Indeed, the center where PRFA were realized probably constitutes a confounding factor for hospitalization length of stay. There were significantly more primary lesions in the gelatin group and consequently a higher proportion of patients with respiratory comorbidities, including emphysema. Therefore, patients with a small well-tolerated pneumothorax were frequently kept under surveillance for an extra night at the CHU. At ICO, patients with a mild and well-tolerated pneumothorax were in most cases discharged at day 1 with instructions.

Bacterial lung infection incidence is similar to other studies without any embolization technique, around 6 % [28]. Bacterial lung infection can be very poorly tolerated in patients with respiratory comorbidities and lead to serious complications development (bacteremia, pseudoaneurysm, etc.). Three main risk factors of bacterial lung infection following PRFA have been suggested: emphysema, pulmonary radiotherapy history and primary neoplastic lesion [28−30]. In the 3 months following the procedure, our study found three bacterial lung infections in the gelatin group (7 %) and none in the control group. These three patients received antibiotic treatment and had favorable evolution within few days. In the present study, primary neoplastic lesion proportion was higher in the gelatin group than in the control group. Studies using the gelatin sponge embolization technique after a lung biopsy [31,32] or PRFA of lung lesion (3,10) have not shown an increase in postprocedural bacterial pneumopathy. Systematic prophylactic antibiotics didn't demonstrate a decrease in lung infection rate after PRFA of lung neoplastic malignancy [6,15,30]. In our study, antibiotics administration was not systematic, antibiotics were only given after PRFA if bacterial pneumopathy was diagnosed.

In the present study, no embolic complications occurred. CuraSpon® was originally developed as a vascular embolization agent. Its use as a technique to reduce chest tube placement rate should therefore not lead to further iatrogenic complications. Indeed, the most feared complication with using gelatin sponge embolization technique is migration of embolization material into pulmonary veins and then into systemic circulation [33]. Izaaryene et al. suggested that there is no risk of migration of endovascular material due to thrombosis of lung vessels in the treated area [3]. Furthermore, this risk could be reduced with using the gelatin sponge torpedoes technique compared with gelatin sponge slurry. It is very important to remember that the technique using gelatin torpedoes must be carried out with care. The radiologist must place the gelatin torpedo slowly and pushing the saline solution into the coaxial sheath without excessive pressure.

This study had several limitations: small sample size, two center study, retrospective data collection, no propensity score. Moreover, both groups had some significant differences with almost all gelatin torpedoes embolization techniques being performed by experienced radiologists, under CT guidance and at the CHU. Patients with three or more lesions treated during the same procedure were excluded, although they are highly prone to pneumothorax requiring chest tube placement. Patients who had biopsy and/or fiducial placement were not excluded, although these parameters may influence the occurrence of pneumothorax.

The gelatin embolization technique resulted in a significant decrease in chest tube placement incidence after PRFA of lung lesion in our patient population. The gelatin sponge has several advantages, as interventional radiologists are used to this material. Moreover, gelatin sponge torpedoes are easy to prepare, inexpensive and have few adverse effects. Indeed, no systemic or pulmonary artery embolic events were reported in the present study, as other studies using the gelatin embolization technique after biopsy or PRFA of a lung lesion. However, more studies are needed to prospectively compare the efficacy and the safety profile of the gelatin torpedoes embolization technique.

5. Conclusion

After PRFA of lung neoplastic lesion, the gelatin torpedoes embolization technique of radiofrequency probe path reduced chest tube placement rate in our patient population, without significant decrease in hospital length of stay. No major complications, particularly embolic ones, occurred in the gelatin group. Gelatin sponge is inexpensive and radiologists are used to this material in current practice. This embolization technique can contribute to reduce chest tube placement rate and its own additional iatrogenic complications such as infection, bleeding and pain. Consequently, further studies are needed to prospectively compare efficacy and safety profile of different embolization techniques with each other.

Human and animal rights

The authors declare that the work described has been carried out in accordance with the Declaration of Helsinki of the World Medical Association revised in 2013 for experiments involving humans as well as in accordance with the EU Directive 2010/63/EU for animal experiments.

Informed consent and patient details

The authors declare that this report does not contain any personal information that could lead to the identification of the patient(s) and/or volunteers.

Funding

This work did not receive any grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Pauline Graveleau: Conceptualization, Investigation, Writing – original draft, Writing – review & editing. **Éric Frampas:** Writing – original draft, Supervision, Validation. **Christophe Perret:** Supervision, Validation. **Stéphanie Volpi:** Supervision, Validation. **François-Xavier Blanc:** Supervision, Validation. **Thomas Goronflot:** Formal analysis, Validation. **Renan Liberge:** Conceptualization, Methodology, Writing – original draft, Supervision.

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