PERCUTANEOUS ABLATION OF MALIGNANT THORACIC TUMORS*

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Lung cancer is the leading cause of death related to cancer. Fifteen to thirty percent of patients with a localized lung cancer are actually inoperable as they present with poor general condition, limited cardiopulmonary function, or a too high surgical risk. Therefore, minimally invasive treatments are needed and percutaneous ablation seems an attractive option. Thermal ablation can be performed by delivering heat (radiofrequency, microwave, laser) or cold (cryotherapy) through a needle inserted into the tumor under CT guidance. The ideal lesion is less than 2 or 3 cm in diameter. Success of percutaneous thermal ablation appears to be close to those of surgery for localized lung cancer. Nevertheless, studies are still needed to definitely assess the role of ablation compared to other emerging techniques, as stereotactic radiotherapy as well as potential synergy with other treatments.

Key-word: Lung neoplasms, therapy.

Lung cancer is the leading cause of death related to cancer and accounted for 29% of cancer deaths in the U.S. in 2009 (1). Eighty percent of lung cancers are non-small cell lung cancer-type (NSCLC). Surgical treatment combining lobectomy or pneumonectomy and hilar and/or mediastinal lymphadenectomy remains the only proven curative treatment of stage I–II NSCLC. However, 15-30% of patients may not benefit from surgery, most often due to poor general condition, comorbid cardiopulmonary disease as insufficient pulmonary reserve, or a high surgical risk (1-5).

The lungs are the second most frequent site of metastases of extra-pulmonary cancers after the lymphatic system. The lungs are the only site of metastasis in approximately 20% of patients after resection of the primitive neoplastic lesion. When the number of lung metastases is limited, their surgical resection is associated with improved survival (1). Unfortunately, as the same exclusion criteria for surgery mentioned above also apply, alternative therapies must be considered, including external beam radiation therapy with or without chemotherapy, improving modestly survival, often with significant toxicity to the patient (2, 3).

Therefore, minimally invasive treatments are needed and percutaneous ablation seems an attractive option. After preliminary studies on the electrochemical polarization of cancers, new percutaneous therapeutic modalities have emerged, including percutaneous brachytherapy (6) and thermal ablation of tumors by radiofrequency (RF) or other sources of energy (7). Thermal ablation is currently used to treat focal malignant lesions located in the liver, kidney, breast, thyroid, head and neck, chest and bones, acting as a substitute or adjunct to other therapeutic modalities (8). Percutaneous thermal ablation is a technique that seems particularly well suited to treat lung tumors, the insulating effect of air in normal lung tissue surrounding the lesion acting like an oven by concentrating the heat in the target tumor (9). Therefore, for a given level of energy, the ablation volume is wider in the lung than in other soft tissues. Moreover, the normal lung parenchyma heals quickly after a thermal injury, and damage to surrounding healthy lung is consequently minimal (9). Theoretically, the main advantages of percutaneous thermal ablation techniques include: relative sparing of healthy tissue which is important to treat patients with reduced cardiopulmonary reserve, reduced morbidity and mortality, faster recovery and earlier discharge from hospital, lower cost, possibility of outpatient treatment, potential synergy with other treatments, and possibility to repeat ablation sessions on the same lesion (10).

Types of energy

Thermal ablation of tumors located in the lung, chest wall, pleura or mediastinum has been safely performed under CT guidance, mainly with the RF energy so far. Other energy sources are available, including microwave, cryoablation and laser (2, 7, 10, 11). The type of energy that can be used will depend on the patient, location and nature of the tumor, treatment goal, and operator experience or preference.

Radiofrequency

The RF energy used in tissue ablation is a sinusoidal current from 400 to 500 kHz issued by an electrode/needle positioned in the target lesion. The RF ablation (RFA) probe acts as the cathode of an electrical circuit that is closed by dispersive electrodes applied on the patient’s thighs (unipolar system). On a few millimeters around the needle, the ionic agitation resulting from the alternating current produces a resistive heating by friction between the molecules. The heat is then transmitted by thermal conduction to the surrounding tissues, causing coagulation necrosis within 1 to 2 cm. The goal is to increase tissue temperature between 50 and 100°C for 4-6 minutes, which is sufficient to cause irreversible cell damage. In contrast, temperature above 105°C causes boiling, vaporization and carbonization of tissue which, by increasing the impedance, decreases the transmission of energy and thereby the size of the ablated area. Therefore manufacturers had to commercialize various types of RFA devices to overcome this limitation and to increase the size of the ablation zone. Some needle designs allow deployment of the tip into multiple electrodes in an “umbrella” – or “bouquet of flowers” – like mode, allowing a larger volume of thermal injury, which can reach up to 5 cm in diameter (8) (Fig. 1). Other devices or technical algorithms allowing larger thermal injury have also been developed, including needles having an internal cooling and allowing RF energy administration without reaching 100°C in contact of the needle, pulsed RF energy administration, or injection of saline into the lesion (3, 8) (Fig. 1, 2). When treating a large lesion, it may be necessary to use multiple needles, which had to be activated sequentially rather than...
Cardiologist (14, 15). Bipolar systems having two active electrodes inserted into the lesion are now commercially available, overcoming the need for dispersive skin electrodes.

Microwave

Thermal ablation by microwave (MW) is a more recent technique using an electromagnetic energy from 900 to 2450 MHz frequencies that increases the temperature of tissue by stirring the molecules of water (10).
The electromagnetic nature of the MW overcomes the problems due to impedance increase secondary to tissue carbonization that may be observed with RFA, and results in a larger ablation volume and safety margins (16). MW ablation (MWA) is therefore less sensitive to the heat-sink effect than RFA, as higher temperature can be reached (up to 150°C), but this may be associated with an increased risk of vascular thrombosis (17). Other advantages of MWA are faster rise of temperature, a more spherical pattern of ablation, ability to activate multiple antennas simultaneously, reduced procedure time, no risk of skin burn on the thighs (no dispersion electrode)

Fig. 2.— Radiofrequency ablation. A: Preablation CT image shows a 14 mm squamous cell lung carcinoma (arrow) in the left upper lobe. B: Perprocedure CT image shows a single straight Cool-tip needle transfixing the lesion (arrow). C: Control CT image obtained at the end of the procedure shows a slight ground-glass halo (arrow) of 10 mm thickness around the lesion. Note also a small pneumothorax (arrowhead).

Fig. 3.— Heat-sink effect. Squamous cell lung carcinoma in the left upper lobe treated with RFA using a Cool-tip needle. Coronal reformat in mediastinal window shows that the margins of ablation are oval in shape. Safety margins at the upper and lower portions of the lesion (long arrows) are flattened and thinner when compared to the internal and lateral margins (arrowheads). This is due to the presence of vessels above and below the lesion, that are responsible for heat loss (heat-sink effect) and potentially resulting in incomplete ablation in those areas.
MWA would therefore be an ideal technique in case of lesion that is more than 4 cm in diameter, in contact with vessels larger than 3 mm in diameter, in patients with limited respiratory function, or in case of recurrence after thermal ablation performed by another type of energy (18).

Cryoablation

Cryoablation is tissue ablation using cold, a temperature drop of at least -20 to -25°C being lethal for tissues. Cryoablation provides a wide ablation zone in a short time, through various direct and indirect mechanisms, including protein denaturation, breakdown of extra- and intra-cellular membranes, and ischemia. The treatment can be monitored in real-time under US, CT or MR, through visualization of the ice ball whose outer boundary corresponds to the 0°C isotherm, while the isotherm -20°C is located approximately 5 mm inside the latter (18). However, whereas the ice ball is clearly identifiable in the chest wall or mediastinum on CT, it may be less visible in the lung parenchyma because of the and less pain when tumor is in contact or located in the chest wall. There is also no interference with electromagnetic waves used in MRI, allowing real-time monitoring of treatment efficacy under MR. Interference with pacemakers/defibrillators are also less important provided that the treatment area is more than 5 cm away from the heart.

Fig. 4. — Microwave ablation. Left lower lobe metastasis from an osteosarcoma of the lower limb. A: The lesion (arrow) is transfixed by the straight MW antenna. B: Control CT image obtained at one month after ablation shows a larger thermoablation when compared to (a). Note small bubble-like lucencies inside the lesion. C: Control CT image obtained at 3 months in mediastinal window and after IV contrast medium administration shows a non enhancing lesion that is smaller compared to B. D: Follow-up PET-CT images at 6 months show no FDG uptake and no sign of recurrence in the ablation area.
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impedance, the possibility to moni-
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MR, and less aggression to sur-

rounding tissues.

Others

Irreversible electroporation is a

new non-thermal ablation technique,

creating permanent pores in cell

membranes, leading to cellular de-

regulation and apoptosis. It uses a

high voltage electric current, requir-
ging general anesthesia and cardiac

monitoring. The application of this
technique in the lung is still prelimi-

ary (22). Advantages over other ab-
lation techniques would be absence

of sensitivity to the heat-sink effect, a

shorter treatment time and less fi-
brous scarring (23).

High intensity focused ultrasounds

are another ablation technique, but

not used in the thorax so far.

Indications

The therapeutic approach to any
tumoral lesion must be discussed in

multidisciplinary oncologic meet-
ings, the respective roles of each

therapy evolving continually accord-
ing to their own progress. It is im-
portant to emphasize that, similar to sur-
gery, ablation provides only a local

control of the disease. The main indi-
cations for ablation are stage I or II

NSCLC and recurrent or limited pul-

monary metastatic disease in pa-

tients that are inoperable or refuse

surgery. In case of NSCLC, surgery

should always be offered as first-

line, lobectomy with lymph node re-

vision being superior to sub-lobar

resection and therefore ipso facto
to percutaneous ablation (3). Regard-
ing metastasis, nature of the primary
cancer and its local control are im-
portant factors to consider. Thus, as

for surgery, metastatic colorectal
cancer and sarcoma are among the

most suited conditions for ablation.
The maximal number of metastasis

that can be ablated is not strictly de-

fined, varying from three to six ac-

cording to the majority of the au-

thors.

The ideal target lesion for ablation

is a lesion measuring less than 3 cm
diameter, and not in contact with

large vessels or bronchi, mediasti-
num and chest wall (2, 13, 24-30).

More uncommon indications are

reported in the literature, including

palliation of symptoms such as pain,
cough or hemoptysis, recurrent
disease in a radiation field, or tumor
debulking (2, 3, 14, 28, 31-34) (Fig. 5).

Contraindications

The contraindications are basic-

ally the same as for percutaneous

transthoracic biopsy (PTT8). Coagu-

dation disorders must absolutely be

controlled. Severely reduced pulmo-
nary reserve (FEV1 < 0.6 L), single

lung or pulmonary hypertension are

not absolute contraindications (3, 35)
(Fig. 6). General anesthesia or
deep conscious sedation can solve

problems in non-cooperative pa-
tients or patients presenting with

intractable cough. An acute pneumo-

nia in contact with the tumor must

low density of air around the ther-

molesion (Fig. 5). The anesthetic ef-

fect of cold on tissues and nerves is a

prominent advantage, making the
technique particularly suitable for

the treatment of lesions located in

the chest wall or close to the pleu-

ra (11). Finally, the associated antitu-
moral immune response would be

more important than for other abla-
tion techniques, and preservation of

tissue architecture allows better cel-

lar repopulation of healthy peritu-

lar tissues. However, cryoaulation
carries an increased risk of

bleeding, because it has no cautera-

ization effect on the vessels. When

frozen, a lesion is more susceptible
to trauma and can fracture. The in-

creased risk of bleeding must be

considered in patients with precari-

ous lung function (20). Similar to the

heat-sink effect for RF, the technique

is susceptible to a cold-sink effect by

blood flow through vessels larger

than 3 mm in diameter. Though the

experience is still limited in the tho-

rax, cryoaulation seems a safe tech-
nique in case of parietal lesion or

peripheral pulmonary lesion (21).

Laser

Laser interstitial thermotherapy

(LITT) delivers a high energy laser ra-
diation (Nd:YAG laser) into the tumor

via optical fibers. The tip of the fibers

is terminated by a diffuser that emits

laser light on an effective distance of

12 to 15 mm (17). Since heat diffuses

slowly towards the periphery of the

lesion, an exposure time of 10 to 30

minutes is required, depending on the

size of the lesion, to obtain a suf-

ficiently high temperature to induce

a coagulation necrosis. The tech-
nique is not currently widely used in

the thorax despite reported results
close to ablation with other types of

energy, probably because of the

complexity of the procedure and the

higher caliber of the material. The

main advantages of LITT versus RFA

are the independence from tissue

impedance, the possibility to moni-
tor the procedure in real time under

MR, and less aggression to sur-

rounding tissues.

Fig. 5. – Cryoaulation. Cryoaulation of a painful metastasis

invading the chest wall. The margins of the oval ice ball are per-

fectly delineated allowing to check the proper covering of the
tumor and to control the safety gap with adjacent vulnera-
sues, including the spinal cord. For optimal thermal protection

of the spinal cord, thermosensors were inserted into the foram-

ina and insulation of the spinal canal was achieved with epidural

CO2 dissection (not shown). Courtesy from Afshin Gangi, Uni-

versity Hospital of Strasbourg, France.
be treated before ablation in order to prevent the spread of the thermal injury to non-tumoral lung (2). Ideally, patients with pacemakers should better be treated with cryoablation or MW, which have less interferences than RF on these devices.

Procedure

Confirmation of the tumoral nature of the target lesion should be obtained before planning the procedure. Whatever the type of energy used, the procedure is usually performed under conscious sedation or general anesthesia, depending on the patient, type of lesion and the choice or experience of the operator (10, 11, 19). At the minimum, the patient is put under oxygen administration with continuous monitoring of cardiorespiratory parameters. When using RF, a minimum of two dispersive electrodes are carefully pasted on the thighs. The parietal pleura is anesthetized and systemic analgesics are administered, as thermal ablation of parietal lesions or close to the pleura can be painful during or after the procedure. When treating a lung tumor close to the pleura, an artificial pneumothorax can be obtained to reduce the pain (36) (Fig. 7).

Precautions, technical ease and procedure of the needle/antenna placement are similar to those of PTTB (37). When multiple needles are needed to treat the whole lesion, they should all be correctly positioned in the target before applying any power to any needle. Their precise deployment is greatly facilitated by the use of fluoro-CT, and optimal positioning relative to the lesion and non-target organs should be confirmed by MPR views (38).

Duration and number of treatment applications depend first on the type of energy system used, and secondly on the size and morphology of the target lesion. The shape of each ablation zone is specific to each device and is generally oval in the axis or perpendicular to the axis of the needle. The criteria for treatment success vary from one system to another, some being based on an abrupt increase of impedance (roll-off), while others are based on the intratumoral temperature (70°C ideally). Similar to surgical margins, it is of utmost importance to ablate an area of healthy tissue around the lesion. Systematic margins of 0.8 to 1.0 cm are recommended since microscopic extension around of the lesion cannot be predicted based on CT images. Those margins appear as a rim of ground-glass that corresponds to the combination of coagulation necrosis, inflammation, congestion and pulmonary hemorrhage (Fig. 2, 3, 6, 7 and 8). This rim should be correctly identified in all three dimensions (Fig. 3 and 8). Studies have reported more than 80% of treatment failure when the rim of ground glass was not identified on control CT (39, 40). When the total area of the thermal injury is four times that of the tumor, the success rate of complete necrosis is 96% whereas it falls to 80% if this proportion is not reached (41). Similarly, when the ablation volume is more than three times the tumor volume, tumor destruction is complete in 83% against 61% when this proportion is not reached (27).

If the lesion is in contact or near the mediastinum, particularly when close to vascular structures, a heat-sink effect can occur. Contact with vessels larger than 3 mm or large caliber bronchi should encourage the use of MW or cryoablation that are less sensitive to heat-sink effect than RF. When necessary, an intravascular pneumothorax can be created to separate the tumor from the heart or great vessels. On the other hand, esophagus, trachea and nerves (mediastinal and parietal, particularly the brachial plexus) are sensitive to thermal ablation, and hydrodissection using glucose fluid or CO2 dissection can be performed to isolate the sensitive structures from the heat source.

Finally, skin tissue at the puncture site should always be controlled, as they are also sensitive to thermal damage. When treating a superficial lesion, mechanisms of local cooling or heating depending on the type of energy should be used to protect them.

At the end of treatment, some devices allow a cauteryization of the intrapulmonary needle tract to reduce the risk of bleeding, pneumothorax, and especially of tumor dissemination.

The patient is monitored afterwards in the recovery room. A chest radiograph is obtained 2 to 4 hours after the intervention. Painkillers will be administered on demand, and anti-inflammatory drugs are often administrated to prevent the postablation syndrome. Prophylactic administration of antibiotics is controversal. Depending on the type of anesthesia, patients are discharged from hospital either on the same day, either 24 or 48 hours later.

Results

Primary tumors

Complete ablation rate was around 90% in a review of the literature.
close to those of surgery, keeping in mind that the majority of the treated patients present with contraindications to surgery (Table I).

**Pulmonary metastases**

After surgical resection, survival of patients with pulmonary metastases is 36, 26 and 22% at 5 years, 10 years and 15 years, respectively. In case of incomplete resection, survival drops to 13 and 7% at 5 and 10 years, respectively (43). After percutaneous ablation of pulmonary metastatic lesions, the survival is 64 to 78% at 2 years and 27 to 57% at 5 years (26, 29, 30, 41, 44) (Table II). Results are significantly higher in case of combined ablation / chemotherapy than chemotherapy alone (87 versus 33%) (45).

The overall results of percutaneous ablation are difficult to compare with those of other therapies, particularly surgery, due to differences in patient population. Indeed, the vast majority of patients treated by surgery have lung cancer limited to the lung. In this respect, percutaneous ablation appears to be a valid alternative for patients who cannot undergo surgery.

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Fig. 7. — Sensitive structures isolation. A: Preablation CT image shows a 15 mm adenocarcinoma (arrow) close to the pleura in the left upper lobe. B: Apparition of a self-limited pneumothorax after insertion of the MW antenna. This iatrogenic complication had the benefit of holding the site of ablation off the sensitive parietal pleura and chest wall, and thus protecting against per- and post-procedural pain. Note ground-glass halo surrounding the treated lesion. C: Control CT image obtained at 3 months shows a smaller and denser lesion compared to B, also showing more angular contours. Note a small cavitation in the right part and aerated ghost path positions of the MW antenna in the left part of the lesion.
After ablation, cancer-related survival is the order of 83-93% at 1 year, 68-75% at 2 years and 59-61% at 3 years (25, 47, 48). Prospective controlled studies are still needed to definitely assess the role of ablation. Studies are also needed to investigate the theoretical synergistic effects of combining percutaneous ablation and radiotherapy, including stereotactic radiotherapy (42, 49). For stage I and II tumor, the first studies of such combined treatments reported a survival of 87, 70 and 57% at 1, 2 and 3 years, respectively, that may be superior than after percutaneous ablation alone (2, 13, 28). The addition of chemotherapy to percutaneous ablation seems also to increase survival in patients with NSCLC.

**Complications**

Percutaneous ablation procedures are well tolerated in the hands of an experienced operator. Complications are usually minor and major...
complication rate is seen in less than 10% (3, 50, 37). A mortality rate from 0.4 to 2.6% is reported, most often due to bleeding, pulmonary sepsis, ARDS, heart failure, or pulmonary embolism (4, 28, 40, 50).

Although the procedure is well tolerated, the patient may present with mild to moderate pain [2, 38]. Cryotherapy has the advantage of being less painful than the techniques using heat when treating peripheral or parietal lesions.

Pneumothorax is the most common minor complication (10-50%) (Fig. 2, 7 and 9). Risk factors and prevention are similar to those of PTTB. The rate of chest drainage is also similar to that reported after PTTB (10-30%) (3, 40).

Post-ablation syndrome, presenting with fever, cough, chills, vomiting and malaise, is reported in up to one third of cases and may last from 1 to 7 days. Treatment is strictly symptomatic. The need for prophylactic antibiotics administered just before the intervention and during the next 5 days is still controversial. Some authors recommend it particularly in patients with prosthetic heart valve or artificial joints (21). Pneumonia is reported in up to 22% of cases, most often in cases of tumor in a central location, associated with retro-obstructive pneumonia, or in case of underlying chronic lung disease (3, 21).

Table I. — Percutaneous ablation of NSCLC.

<table>
<thead>
<tr>
<th>Patients</th>
<th>Lesions</th>
<th>Mean size (cm)</th>
<th>Global survival (%)</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1 y</td>
</tr>
<tr>
<td>Akeboshi (24)</td>
<td>RF</td>
<td>10</td>
<td>2,7 ± 1,3</td>
</tr>
<tr>
<td>Grieco (13)</td>
<td>RF*</td>
<td>37</td>
<td>2,1 ± 1,1</td>
</tr>
<tr>
<td>De Baère (41)</td>
<td>RF</td>
<td>9</td>
<td>1,7 ± 0,9</td>
</tr>
<tr>
<td>Simon (28)</td>
<td>RF</td>
<td>75</td>
<td>2,7</td>
</tr>
<tr>
<td>Pennathur (61)</td>
<td>RF</td>
<td>19</td>
<td>2,6</td>
</tr>
<tr>
<td>Hiraki (62)</td>
<td>RF</td>
<td>20</td>
<td>2,4</td>
</tr>
<tr>
<td>Lencioni (47)</td>
<td>RF</td>
<td>33</td>
<td>1,7</td>
</tr>
<tr>
<td>Wolf** (48)</td>
<td>MW</td>
<td>50</td>
<td>3,5 ± 1,6</td>
</tr>
<tr>
<td>Lanuti (42)</td>
<td>RF</td>
<td>31</td>
<td>2</td>
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<tr>
<td>Ambrogi (25)</td>
<td>RF</td>
<td>57</td>
<td>2,6</td>
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* + Radiotherapy.
** Includes NSCLC and metastases.

Table II. — Percutaneous ablation of lung metastases.

<table>
<thead>
<tr>
<th>Patients</th>
<th>Lesions</th>
<th>Mean size (cm)</th>
<th>Global survival (%)</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1 y</td>
</tr>
<tr>
<td>Akeboshi (24)</td>
<td>RF</td>
<td>21</td>
<td>2,7 ± 1,3</td>
</tr>
<tr>
<td>Yan (30)</td>
<td>RF</td>
<td>55</td>
<td>2,1 ± 1,1</td>
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<tr>
<td>De Baère* (41)</td>
<td>RF</td>
<td>51</td>
<td>1,7 ± 0,9</td>
</tr>
<tr>
<td>Simon (28)</td>
<td>RF</td>
<td>18</td>
<td>2,7</td>
</tr>
<tr>
<td>Yamakado (29)</td>
<td>RF</td>
<td>71</td>
<td>2,4 ± 1,3</td>
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<tr>
<td>Wolf** (48)</td>
<td>MW</td>
<td>50</td>
<td>3,5 ± 1,6</td>
</tr>
<tr>
<td>Lencioni (47)</td>
<td>RF</td>
<td>73</td>
<td>1,7</td>
</tr>
<tr>
<td>Gilliams (26)</td>
<td>RF</td>
<td>37</td>
<td>1,8</td>
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<td>Rosenberg (44)</td>
<td>LITT</td>
<td>64</td>
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<tr>
<td>Pallusiere**</td>
<td>RF</td>
<td>189</td>
<td>1,5</td>
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</tbody>
</table>

* Includes nine patients with NSCLC.
** Includes NSCLC and metastases.
Micro-emboli of gas, detectable by carotid US, have no neurological impact (3). A careful technique should reduce the risk of tumor dissemination during the procedure (17).

Despite a possible transient decrease during the first 3 weeks after ablation, the overall respiratory function tested at 3, 6 or 12 months after the intervention shows no degradation (25, 41, 42, 47).

Fig. 9. — Bronchopleural fistula. Patient with past-history of multiple sequential lung metastases from a renal cancer. He underwent serial lobectomy and multiple surgical wedge resections. A few years later, two new metastases were ablated using a Cool-tip RF device. In the recovery room, the patient presented with an episode of carbonarcosis requiring positive pressure ventilation. A bronchopleural fistula developed and was responsible for right pneumothorax and parietal emphysema that took 3 weeks to recover. Control CT image shows the fistula (arrow) between a bronchus and the cavitated treated lesion. Note a small remaining pneumothorax (arrowhead).

Fig. 10. — Cavitation and linear scar after ablation. A: Control CT image performed 1 month after ablation shows an asymptomatic cavitation after ablation of a squamous cell lung cancer of the left upper lobe. Follow-up was uneventful. B: Control coronal CT coronal reformat obtained at 10 months shows a simple linear scar (arrow). PET-CT showed no FDG uptake (not shown).
Follow-up

Early detection of residual or recurrent tumor is crucial for proper management of the patient, possibly resulting in a new session of ablation. Follow-up imaging of ablation is difficult and must be known by all interventional and non-interventional radiologists. Mainly contrast-enhanced CT and PET-CT are used for the follow-up.

The lesion size alone is not considered as a reliable criterion of complete necrosis during the first 6-12 months. Consequently RECIST is rarely used after ablation and follow-up evaluation criteria should be adapted to the ablation technique (54). Overablation technique to obtain safety margins and inflammatory secondary to thermal injury result in a thermolesion larger than the target tumor (Fig. 4, 7 and 8). The maximum size is reached within 24 to 48 hours or during the first week after ablation, although growth in the next few weeks has been reported (55). Subsequently, the lesion remains stable or decreases in size, but the parameters of shrinking are not established so far (2). Any increase in size after one week and a fortiori 3 or 6 months after ablation should indicate tumor recurrence. While retracting, the lesion shows more angular contours, leaving eventually a linear scar (Fig. 7 and 10). The final sequella may however remain nodular, especially if the target lesion was initially larger than 2 cm, and sometimes even larger than the initial lesion (21, 56).

Enhancement after IV injection of contrast medium should also be evaluated, as an area of complete necrosis theoretically shows no contrast uptake. Enhancement greater than 10-15 HU or more than 50% of the enhancement of the target lesion before ablation should be suspicious of recurrence, especially when nodular, central, irregular or eccentric, or in contact with a vessel. Enhancement of inflammatory granulation tissue around the ablation zone can be seen as a peripheral rim during the first 6 months (Fig. 11). Bubble-like lucencies or cavitation in the lesion, usually asymptomatic and considered as a sign of good prognosis, can be visible in 30 to 50% of cases (Fig. 10 and 11). Cavitation usually disappears after 6-9 months (48, 55, 56). Finally, inflammatory hilar and mediastinal lymphadenopathies may appear during the first 3 months and then regress from 6-month (21).

It is important to note that the gradual evolution of the ablation lesion to a fibrous linear scar, cavitation or atelectasis does not exclude the possibility of a subsequent local recurrence, emphasizing the importance of a continuous follow-up (56).

CT morphological analysis has limitations as an incomplete treatment may only be depicted after several months of follow-up in some cases (41, 56). MRI could better appreciate an early recurrence thanks to its superior contrast resolution (7, 14, 21). Experimental results of diffusion MRI seem particularly promising by detecting recurrences within 3 days after ablation (57).

PET-CT is more sensitive than CT alone in detecting residual tumor or recurrence in oncologic practice (24). The role of PET-CT in the early period after ablation, however, is debated in the literature. While some authors suggest its utility for the early detection of recurrence (12 to 24 hours), false positive results due to local inflammation or lymph nodes that may be found in 10-20% of cases suggest that PET-CT should better be obtained 3 to 6 months after treatment (21, 58, 59) (Fig. 4).

Various follow-up algorithms are proposed in the literature. In practice, as an example, CT is often performed at 24 hours, 1 month, and then every 3 months during the first year and every 6 months during the second year. CT will be combined with PET at 3- or 6-month, then every 6 months, or when CT is equivocal.

Future

Percutaneous ablation is still currently considered as a stand-alone technique of treatment. The true position of ablation in the complex oncologic armamentarium remains to be defined. Future goals are to evaluate the long-term results of ablation compared to other techniques such as surgery and stereotactic radiotherapy, and to evaluate the association of ablation with other type of treatments, including adjuvant or neoadjuvant chemotherapy, and targeted therapies reducing tumor vascularization (60).
References