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Review Article

Image-guided lung tumor ablation: Principle, technique, and current status

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Abstract

Image-guided tumor ablation for lung malignancies has emerged as a treatment modality for medically inoperable patients. Overall, image-guided lung tumor ablation is a minimally invasive procedure that has an acceptable safety profile and less impact on lung function. This is important for patients with poor pulmonary and/or cardiac functions or with multiple comorbidities, which prevent them from undergoing surgery, chemotherapy, and radiation therapy. Herein, we review the principle, techniques, clinical application, and patient outcomes of image-guided lung tumor ablation.

Keywords: ablation; cryoablation; lung; microwave; radiofrequency; tumor

1. Introduction

The lungs are a common site where malignancy occurs frequently. Lung cancer is the primary cancer, with the highest mortality rate being reported in Taiwan; it accounted for 20% of all cancer deaths in 2010.[1] Although the 1-year survival rate for lung cancer has increased, the overall lung cancer survival rate remains low with the existing treatment methods; a 17% overall 5-year relative survival rate has been reported for all stages combined, a 52% survival rate for localized disease, a 25% survival rate for regional disease, and a 4% survival rate for distant disease.[2] The lungs are also a common site for the spread of metastatic tumor that originates from other parts of the body. Approximately 20−50% of patients who die from tumor malignancies are found to have pulmonary metastases.[3]

Surgical resection is the first-line treatment for early-stage non-small-cell lung cancer (NSCLC), and pulmonary metastasectomy is performed for certain primary tumors such as hepatocellular carcinoma; in general, metastasectomy is associated with prolonged survival.[4] However, only 15% of lung cancer patients have localized disease for which surgery is a treatment of option. This is further complicated by a decrease in lung function after surgery, which results in a mean change in forced expiratory volume in 1 second (FEV_1) in 11−25% of patients after lobectomy, in 11−13% of patients after segmentectomy, and in 9% of patients after wedge resection.[5,6] A proportion of individuals with low pulmonary reserve do not meet the criteria for a lung operation, as defined by the American College of Surgeons Oncology Group/National Institutes of Health (NIH) Inoperability Criteria for Lung Surgery.[7]

Medically inoperable patients account for 85% of all lung cancer patients, and may need systemic chemotherapy or external-beam radiation therapy. Radiation therapy has traditionally been used for patients with medically inoperable lung cancer at clinical stage I and clinical stage II. Despite the development of modern radiotherapy techniques such as intensity-modulated radiation therapy, radiation to the lung tissue, which has a low dose tolerance, may still be damaging. Pneumonitis induced by radiation therapy occurs in more than 16% of patients when the V20 exceeds 22%, which may cause serious respiratory distress, requiring hospitalization and intubation, and can be fatal.[8] Moreover, lung function may

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deteriorate after irradiation of the lung; for example, the FEV_1 may decline by 10% after 12−18 months of radiation therapy.[9] These midterm complications and long-term sequelae limit the use of radiation therapy in patients who have poor cardiopulmonary function. Additionally, approximately 43% of patients with lung cancer have a poor performance status of 2−4, which prevents them from receiving surgical, radiation, or chemotherapy treatment, resulting in a bleak 5-year survival rate. Therefore, development of less invasive treatment modalities for patients with localized primary disease is important.

Tumor ablation is a minimally invasive and relatively safe procedure that can be a treatment option for patients who are medically inoperable due to their poor pulmonary reserve. Ablation refers to direct application of chemical or thermal therapies to a specific focal tumor (or tumors) to achieve eradication of the tumor or its substantial destruction.[10] The most contemporary tumor ablation technique is thermoablation; the subtypes are radiofrequency ablation (RFA), microwave ablation (MWA), and cryoablation, which are named according to their energy sources. Ablation techniques used for lung tumors are of two types: image-guided (percutaneous) and thoracoscopic lung tumor ablation. Image-guided lung tumor ablation techniques share the common feature of an energy generator in that it transfers the energy source to the tumor by an image-guided, inserted, needle-like energy "applicator" for a certain period of time, which results in tumor destruction. Ablation has several advantages, including selective damage, minimal morbidity and mortality, decreased loss of lung function (because much of the normal lung tissue is spared), repeatability, lower cost, excellent monitoring during treatment, increased quality of life with less pain, and shorter hospital stays.[7] The present review article covers the clinical application, mechanism, techniques, and outcomes of image-guided ablation of lung tumor.

2. Clinical application

Currently, lung tumor ablation is applied to primary lung cancer and metastatic lung malignancies for curative, symptom relieving, and cytoreduction purposes.[11] Interdisciplinary coordination plays a major role in the selection of patients. Curative ablation is indicated for stage I primary lung cancer patients who are medically inoperable due to their poor pulmonary functional reserve or cardiac comorbidities. Ablation is also performed in patients with lung metastases generated from colorectal and renal cell carcinoma, melanoma, hepatocellular carcinoma, and sarcoma primary tumors. A tumor size of 3.5 cm and the tumor number of 5 are generally considered to be the upper limits for ablation.[12] Patients with symptoms such as chest wall pain due to tumor invasion, hemoptysis, and coughing can also be relieved completely or partially by tumor ablation.[13] A combination of ablation therapies for advanced lung cancer and metastatic lung malignancies may also provide cytoreduction.[14,15]

The absolute contraindication for image-guided lung tumor ablation is the presence of uncorrectable coagulopathies. An international normalized ratio of >1.5, an activated partial thromboplastin time of >1.5 times the normal value, or a platelet count of $<50{,}000/\mu L$ should all be considered for correction. Plavix and aspirin should be withheld for 5 days.[16] Relative contraindications include a poor patient performance status of 3 or more and very limited life expectancy in the Eastern Cooperative Oncology Group.[12] Although ablation has a limited effect on pulmonary function, a low FEV_1 of less than 0.6 L is considered a relative contraindication.[17]

3. Radiofrequency ablation

3.1. Principle

Radiofrequency is the frequency of oscillation in the range of 3 kHz−300 GHz. The RFA applicator serves as an active electrode, and the reference electrode is the grounding pad. In modern RFA, electric fields are established between electrodes oscillate within the radiofrequency range (375−500 MHz). Ions in the tissue then oscillate with the oscillating electric fields, and their friction generates heat. The heat is then dispersed gradually through the tissue by conduction. Additionally, coagulation necrosis occurs after a period of RFA application. At the tumor site, if the tissue temperature remains at approximately 45°C for several hours, irreversible cell damage occurs; at 50°C permanent damage occurs within a few minutes; at 60°C coagulation is induced almost instantly; and at more than 100°C the tissue will vaporize and carbonize. Because carbonizing, also called charring, impedes heat conduction, which plays a major role in heat dispersion throughout the entire lesion, the ideal therapeutic temperature range for RFA is 60−100°C.[5,18] The extent of tissue destruction by ablation is called the ablation zone.

3.2. Equipment and techniques

Currently, there are three major types of equipment systems for RFA: a multitine electrode with temperature control, a multitine electrode with impedance control, and an internally cooled straight electrode. Each type of device consists of an electrical generator, a needle electrode, and a ground pad. The electrode diameter ranges from 14 gauge to 17 gauge. The maximal output of the generator is approximately 200 W (Fig. 1).

Prior to ablation surgery, patients fast overnight and have intravenous access established. The grounding pads are attached to their thighs, and the skin of the planned insertion site is then prepped. Under local anesthesia with or without conscious sedation, the electrode is placed under the guidance of computed tomography (CT). In some institutions, CT-fluoroscopy is utilized to achieve fast and precise electrode insertion. The generator is then turned on to produce the RF electric fields, and heat is generated at the target lesion. After a period of ablation, the patient is transferred to the recovery room for observation, and chest radiography is performed a few hours after the procedure. If no pneumothorax or