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Case Report

High-frequency jet ventilation for minimizing breathing-related liver motion during percutaneous radiofrequency ablation of multiple hepatic tumours

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Movements of the liver caused by spontaneous breathing (during sedation or local anaesthesia) or by ventilation during anaesthesia are a source of concern in CT-guided procedures because of the limited spatial and contrast resolution of unenhanced imaging, artifacts caused by the probes and the relatively low temporal resolution of the fluoroscopy mode. During CT-guided radiofrequency ablation (RFA), it is essential that the lesion can be visualized optimally and that the ablation probe is positioned accurately to avoid non-target injuries. We therefore used high-frequency jet ventilation and general anaesthesia to minimize ventilation-related liver movement and provide optimal conditions for a patient undergoing RFA of hepatic metastases. The technical and anaesthetic considerations are discussed, and a specific limitation of transcutaneous P_{CO_2} measurement during activation of the ablation is reported for the first time.

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Radiofrequency ablation (RFA) is a less invasive alternative to surgery to treat liver tumours with a diameter <4 cm.[1–3] A needle-shaped probe is advanced percutaneously into the centre of the lesion, and activated to denature the tumour proteins by thermal coagulation. Movements of the liver during spontaneous breathing can cause difficulties for the interventional radiologist.[4] In addition, inadvertent movements by a patient undergoing the procedure under local anaesthesia may reduce the accuracy of targeting the tumour and increase the risk of parenchymal injury and haemorrhage.[5] Conversely, general anaesthesia with neuromuscular block allows immobilization of the patient, but large ventilation-induced movements of the liver are still present. Using lower tidal volumes during conventional artificial ventilation has only limited benefit because the associated increase in dead space at the expense of alveolar ventilation inevitably leads to hypercarbia. Apnoea is possible in awake patients for durations <1 min, but this is far too short to be suitable for RFA, where each single probe activation period is longer than 10 min.

High-frequency jet ventilation (HFJV) utilizes very low tidal movements of the lungs, which in turn are associated with smaller movements of adjacent abdominal organs.[6 7] General anaesthesia with neuromuscular block and HFJV has been described as a successful technique for patients undergoing extracorporeal shock wave lithotripsy for kidney stones[8 9] and posterior left atrial catheter ablation.[10]

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This report illustrates the successful application of this anaesthetic technique in a patient who was undergoing RFA of three distinct liver tumours.

Case report

A 64-yr-old male presented with three 18-FDG-PET-positive metastases in the liver after right hemicolectomy for adenocarcinoma. At the time of colonic surgery, the open liver biopsy confirmed that the lesions were malignant. Postoperative systemic chemotherapy failed to reduce lesion diameter below 10 mm. Surgical resection was rejected because of their distribution in both lobes (segments II, IVa, and VII according to the Couinaud classification). These tumours were undergoing treatment with RFA under CT guidance (SOMATOM Definition AS, 40 slice, Siemens, Forchheim, Germany), as they could not be visualized by ultrasound because of a coexisting 'fatty liver'. Each metastasis was treated sequentially by coagulation with a single cool-tip RF electrode (Valleylab, Boulder, CO, USA) for 12 min each during the same session. Considering the time required for identifying, locating, and hitting the targets of more than 20 min each, a total intervention time of 2 h was expected.

One hour after oral premedication with midazolam 7.5 mg, anaesthesia was induced using propofol (TCI initial target concentration 5 $\mu g\ ml^{-1}$, followed by 3 $\mu g\ ml^{-1}$), fentanyl 0.2 mg i.v. followed by an infusion of remifentanil up to 0.15 $\mu g\ kg^{-1}\ min^{-1}$, and neuromuscular block with atracurium (total 75 mg). Standard intraoperative monitoring (ECG, non-invasive arterial pressure, pulse oximetry, capnography, and neuromuscular block monitoring) was applied and transcutaneous P_{CO_2} (Ptc_{CO_2}) measurements (Microgas 7650, Linde, Basel, Switzerland) were performed to enable adjustments of HFJV settings to maintain normocarbia. The patient's trachea was intubated with a conventional endotracheal tube (ETT) of internal diameter 7.5 mm. After intubation, conventional positive pressure ventilation (PPV) was applied (V_T 400 ml, frequency 14 bpm) and maintained for 20 min while preparation and positioning for RFA were established.

During a preliminary spiral CT sequence performed to obtain baseline reference images, the exact measurement of the liver movements during PPV was obtained: a craniocaudal swinging of amplitude 20 mm. HFJV involved placing a jet ventilation catheter (LaserJet, Acutronic MS, Hirzel, Switzerland) into the cuffed ETT. Airway pressure was continuously monitored via a second lumen of the jet catheter, which included automatic cessation of jet insufflations in the case of surpassing a pressure limit of 35 mbar, though airway pressure never exceeded 5 mbar. The proximal outlet of the ETT was kept open to the atmosphere in order to enable free gas egress. Initial ventilator settings (Monsoon Universal Jet Ventilator, Acutronic MS, Hirzel, Switzerland) were $F_{I_{O_2}}$ 1.0, working pressure 1.8 bar, ventilatory frequency 150 cycles min^{-1}, inspiration duration of 50%, and gas conditioning output (moistening and heating) level at 100%. After switching to HFJV, another spiral CT measurement of the amplitude of liver movement showed a caudal displacement of just 5 mm.

Sp_{O_2} remained stable above 97% during the whole procedure, but Ptc_{CO_2} slowly decreased from a baseline of 4.9 to 4.0 kPa, thus requiring a single setting change by decreasing working pressure to 1.4 bar. An attempt to further decrease liver movement by increasing the ventilation frequency to 200 cycles min^{-1} did not yield a significant benefit in terms of further minimizing liver movement, but was instantly followed by an increase in Ptc_{CO_2} from 4.6 to 6.2 kPa and so the initial setting of 150 cycles min^{-1} was restored. Adequate oxygenation and normal carbon dioxide concentrations were maintained for the remainder of the procedure.

We noted that during thermal coagulation, the Ptc_{CO_2} sensor showed a rapidly decreasing value caused by interference from the activated RF probe; this phenomenon

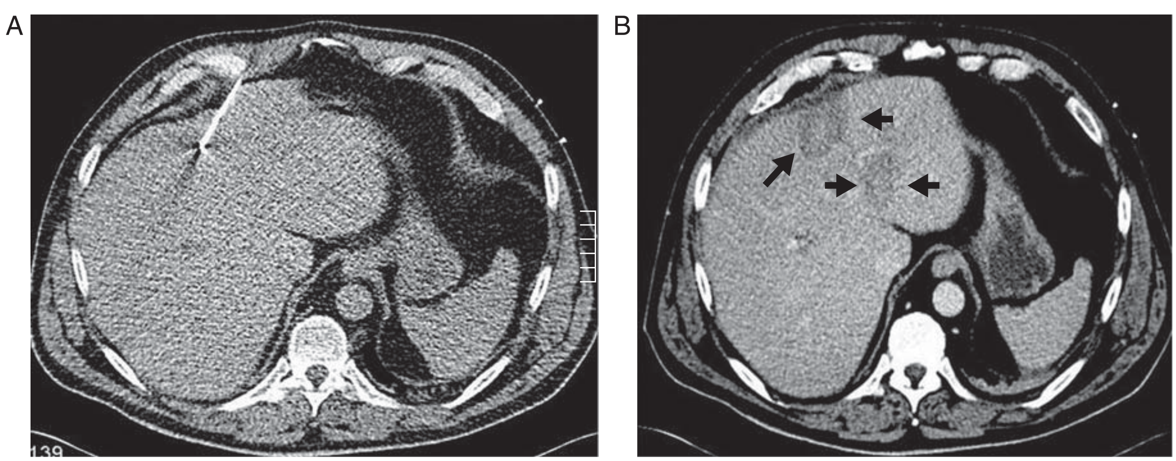

Fig 1 (A) An RF probe has been advanced under CT guidance into a 5 mm colon cancer liver metastasis in segment IV. (B) The completion CT scan confirms the correct ablation areas of this lesion and another one in segment II (arrows).

immediately terminated and the signal normalized within 30 s after cessation of the cauterization. However, the temporary absence of reliable Ptc_{CO_2} readings during the cauterization (12 min) was not of great concern, since there was enough time to find adequate HFJV settings before activation of the RF probe.

The performance of the three RFA sessions was uneventful. At the beginning of the procedure, a contrast-enhanced liver CT was obtained. The first two lesions in the left lobe were accessed by a sub-xyphoidal puncture, and the third one, located underneath the dome of the liver in segment VII, was targeted via a right intercostal and transpleural route after the ventral approach had failed. As the lesions could not be directly visualized in the CT-fluoroscopy mode, anatomical landmarks and their correlation with the lesion location in the immediate pre-interventional CT were utilized to guide the RF probe (Fig. 1). This imaging correlation was facilitated by the stable liver position.

No problems were encountered with haemodynamics, ventilation, airway maintenance, and gas exchange. After removal of the RF probe, a final contrast-enhanced liver CT was performed to document the ablation volumes. HFJV was terminated and emergence from anaesthesia was conducted under careful manual hand-bag ventilation. Tracheal extubation was performed and the patient transferred to the recovery unit. Chest X-rays 2 and 12 h after the procedure revealed linear atelectasis at the right lung base with no evidence of pneumothorax. The patient was discharged from the hospital the following day.

Discussion

At our institution, percutaneous hepatic RFA is carried out under either local anaesthesia with sedation or under general anaesthesia. The choice between the two methods depends on the number, size, and location of the lesions, the expected ease of accessibility, their conspicuousness at ultrasound or CT imaging, and on the preferences of the interventional radiologist and the patient. Under sedation, most patients will be able to hold their breath as long as the procedure is not too painful, and is of short duration; the level of sedation can be adjusted to the patient's individual needs. If the intervention has to be performed under CT control (which has lower temporal resolution compared with ultrasound, but the advantage of better lesion detection), whole liver imaging becomes crucial. In particular, with CT, no 'black' spots due to air or bone ultrasound reflections will appear, and an easier visual monitoring of the ablation process is possible. Hence, avoidance of respiratory movement artifacts, which degrade the image quality, is of great importance. As CT fluoroscopy is not yet a real-time procedure, imaging-directed instrumentation may be problematic if the target is continuously displaced due to respiratory movement. These movements may dictate repeated punctures and thereby increase the risk of complications such as haemorrhage and tumour tract seeding. Exact targeting of the RF probe is essential for the accuracy of the therapeutic effect, and to avoid collateral damage of healthy tissue. HFJV causes much smaller tidal movement of lungs and abdominal organs than PPV, and so may be preferable during RFA. However, awake patients do not tolerate HFJV and it therefore requires general anaesthesia, preferably with neuromuscular block. This increases the overall complexity of the treatment, but offers better imaging of the targeted tissue, a more accurate focusing of the thermal denaturation and a lower risk for parenchymal injury and haemorrhage caused by inadvertent patient movements.[5] HFJV might have further advantages if it is necessary to pass the pleural cavity for targeting cranial liver regions. Under HFJV, peak airway pressure does not exceed 5 mbar, and therefore there is a lower tendency for gas accumulation in the pleural cavity than under PPV with much higher airway pressure.

HFJV can maintain adequate ventilation for almost unlimited durations.[6 11 12] HFJV has been successfully used during lithotripsy to prevent excessive movements of the kidneys and ureters.[8 9] Considering the direct proximity of the liver to the diaphragm, the liver is even more exposed to breathing movements than the kidneys, with an even greater need for reduction of movement. We found only one animal study where liver movements have been studied under HFJV and compared with PPV in dogs.[13] Here the size of the reported movements was up to 12 mm under PPV compared with 2 mm during HFJV. Assuming that humans are more than three times larger than dogs, one can expect to achieve an even larger benefit by changing the ventilation mode to HFJV. This corresponds well with our observation that during HFJV, liver movements decreased by 75% to 5 mm when compared with 20 mm during PPV.

To find the best jet ventilation settings, there is a need to make stepwise adjustments to the working pressure and ventilatory frequency to maintain normocarbia.[11] This is the first report describing the temporary disturbance of the Ptc_{CO_2} reading during activated RF ablation. The accuracy of transcutaneous PCO_2 measurement is debatable and we only had to keep the baseline Ptc_{CO_2} unchanged when compared with the awake value. Therefore, it is not considered necessary to obtain an arterial blood gas value for an *in vivo* calibration. The temporary disturbance of Ptc_{CO_2} readings during the period of RF activation was an incidental finding which has not been previously reported, but if confirmed illustrates a limitation of this monitoring technique. In practice, this was easily overcome by making the necessary adjustments of HFJV before periods of probe activation. Otherwise, capnography was available during PPV, and direct comparisons showed in this case a constant difference of 0.5 kPa higher for Ptc_{CO_2}.

In conclusion, this case illustrates that HFJV under general anaesthesia provided excellent conditions for imaging and treating of hepatic lesions with CT-guided RFA by markedly reducing the amplitude of respiration-related movements of the targeted organ. Further experience is required and prospective studies should be conducted to find the ideal ventilation settings to enable a minimum of organ movement while maintaining adequate gas exchange.

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