

Robot-assisted microwave thermoablation of liver tumors: a single-center experience

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Abstract

Purpose To evaluate and compare the needle placement accuracy, patient dose, procedural time, complication rate and ablation success of microwave thermoablation using a novel robotic guidance approach and a manual approach.

Methods We performed a retrospective single-center evaluation of 64 microwave thermoablations of liver tumors in 46 patients (10 female, 36 male, mean age 66 years) between June 2014 and February 2015. Thirty ablations were carried out with manual guidance, while 34 ablations were performed using robotic guidance. A 6-week follow-up (ultrasound, computed tomography and MRI) was performed on all patients.

Results The total procedure time and dose-length product were significantly reduced under robotic guidance (18.3 vs. 21.7 min, $p < 0.001$; 2216 vs. 2881 mGy×cm, $p = 0.04$). The position of the percutaneous needle was more accurate using robotic guidance (needle deviation 1.6 vs. 3.3 mm, $p < 0.001$). There was no significant difference between both groups regarding the complication rate and the ablation success.

Conclusion Robotic assistance for liver tumor ablation reduces patient dose and allows for fast positioning of the

microwave applicator with high accuracy. The complication rate and ablation success of percutaneous microwave thermoablation of malignant liver tumors using either CT fluoroscopy or robotic guidance for needle positioning showed no significant differences in the 6-week follow-up.

Keywords Interventional radiology · Robotic assistance · Microwave ablation · Liver tumor · CT-guided

Introduction

Microwave ablation is a special form of thermal ablation. It uses alternating electromagnetic waves to induce tissue-heating effects leading to thermal denaturation of solid tumors and the surrounding tissue [1]. It is a therapeutic method for curative or palliative treatment in nonsurgical candidates. Hepatocellular carcinoma and liver metastasis constitute a classic field of application for thermal ablation. Many studies have proven that there are similar survival rates compared to surgery [2,3].

The microwave applicator can be positioned using ultrasound, computed tomography or magnetic resonance imaging [4]. Needle positioning is challenging in the case of barely visible tumors or difficult approaches, and repositioning of the microwave applicator is often unavoidable. Every needle replacement leads to a higher complication rate [5,6]. Using computed tomography-guided applicator positioning, the dose to the patient and interventionalist leaps with increasing complexity [7]. As a result, a relatively high radiation dose can occur in difficult ablation scenarios [8,9].

Modern, robot-assisted CT-based navigation systems allow for precise planning of the applicator approach and the expectable ablation area in a 3D image data record. High

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accuracy and precision are achieved [10]. These systems could potentially lead to a reduced radiation dose for the patient and interventionalist as well as to a lower number of needle replacements and as a consequence to a lower complication rate.

There is only very limited data regarding robot-assisted microwave ablation of malignant liver tumors [11, 12]. Therefore, we report on our results comparing a novel robotic system to the CT-guided fluoroscopic manual approach for needle positioning in microwave thermoablation of malignant liver tumors.

Materials and methods

Study design and participant selection

A single-center retrospective observational study was conducted to assess radiological findings and interventional reports from 64 consecutive CT-guided microwave ablation sessions between June 2014 and January 2015. Before treatment, all patients were reviewed by members of an interdisciplinary tumor board who decided on the indication for microwave ablation. Patients were selected for microwave ablation if surgical resection was precluded. Exclusion criteria were coagulopathy, tumor resectability, unsuitability of the patient to undergo general anesthesia, or multifocal hepatic disease not amenable to complete ablation.

Forty-six patients (mean age 66 years; age range 54–85 years) with primary liver tumors or secondary liver metastases underwent microwave ablation. Thirty-four of the interventional procedures were robot-assisted and 30 were fluoroscopy-guided (Table 1). In all cases, preinterventional MRI with liver-specific contrast media (Primovist, Bayer Schering Pharma, Berlin) had been performed as reference imaging.

In our hospital, all patients who underwent percutaneous ablation of malignant liver tumors without any complications are discharged two days after the CT-guided intervention.

Table 1 Data regarding ablated lesions

Tumor type	<i>n</i>	Manual or guided	
		Manual	Guided
Lung cancer	1	1	0
Breast cancer	2	2	0
Colorectal cancer	12	2	10
Prostate cancer	1	1	0
Hepatocellular carcinoma	48	24	24
All	64	30	34

Peri-interventional imaging

All patients underwent three-phase multi-slice CT (Somatom Sensation 16, Siemens Healthcare, Forchheim, Germany) in apnea immediately before tumor ablation. Contrast-enhanced arterial phase images were generated during injection of 120 mL of nonionic contrast material at a flow rate of 3–4 mL/s using bolus tracking with a threshold of 100 HU. Portal venous phase images were obtained 50 s after the arterial phase scan. At the end of the ablation session, every patient underwent a non-contrast multi-slice CT scan of the liver to detect or exclude any complications.

In three-phase CT, the density values of tumor and liver tissues were measured with circular ROIs (regions of interest) with a size of 1 cm². The density differences between liver tissue and tumor were determined in both the non-contrast technique and the contrast-enhanced phase with the best tumor visibility. The density difference was referred to as the tumor conspicuity (TC). The size of the tumor was measured in the contrast-enhanced phase with the best tumor visibility in the short and long axis. In addition, the shortest distance from the skin to the tumor in axial plane (skin-to-tumor depth) was determined.

Thermoablation procedure

All ablation procedures were performed in general anesthesia by an experienced interventional radiologist. In each patient, microwave ablation was carried out percutaneously using the Acculis microwave tissue ablation system (AngioDynamics, Latham, NY, USA), which operates at 2.45 GHz with a maximum power output of 140 W and uses electromagnetic waves to induce tissue-heating effects leading to necrosis [1]. The standard Acculis microwave applicator with a 1.8-mm diameter and 16-mm active tip was used in all cases. The shaft length (14 or 19 cm) was selected depending on the distance from the skin to the center of the tumor where the active point of the probe should be placed. After needle placement for ablation procedure, the parameters (ablation duration, number of watts) were adjusted depending on the tumor size with the aim to gain a preferable safety distance of 1 cm.

Manual approach

CT fluoroscopy is an acquisition mode that allows continuous image update using in-room table control. After the initial three-phase planning CT, the antenna is placed by an interventional radiologist with repeated checking of the needle position using CT fluoroscopy and if necessary repositioning of the needle until the tumor center is reached. In 13 cases, a verification multi-slice CT scan of the needle placement was then performed to ensure the correct needle position. In the remaining 17 cases, the fluoroscopy images already

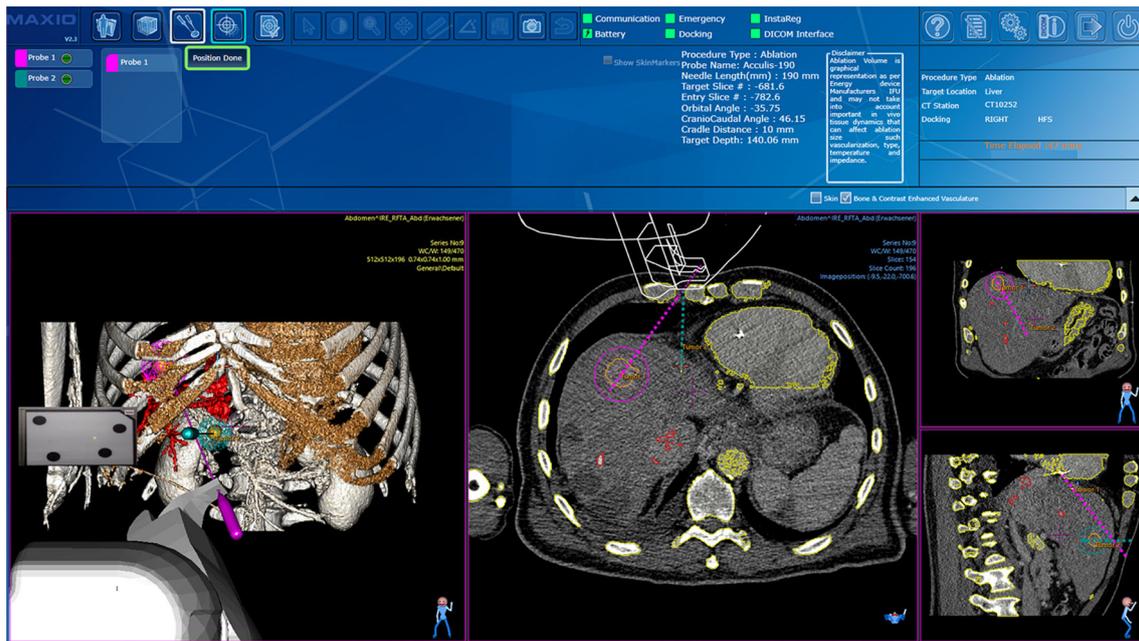


Fig. 1 Planned position of the microwave applicator with the simulated ablation volume (*purple*). The tumor that is manually marked in the 3D image dataset (*orange*) is completely included in the ablation volume

confirmed a correct needle position. All patients underwent a final non-contrast multi-slice CT scan to detect any complications.

Robotic guidance

Before robot-assisted image-guided tumor ablation, all patients were positioned on a vacuum mattress to minimize the movability of the patients between the planning multi-slice CT scan which affects the real-time planning on the robotic system and the positioning of the applicator. Based on the initially performed three-phase CT of the liver, semiautomatic liver segmentation and manual marking of the tumor in a 3D image dataset were performed.

The entry point of the needle in the skin and the target point of the needle tip were determined to plan the access path. A simulation of the ablation volume is used to check whether the previously marked tumor is completely included in the ablation with sufficient safety distance (Fig. 1). This simulation supports the right selection of adequate ablation parameters (ablation duration, number of watts). The robot software performs bone detection and semi-automatic liver segmentation including liver vessels. During planning, warnings are issued automatically if the needle path or ablation volume intersects critical structures, especially liver vessels or bones. After approval of the plan by the radiologist, the robotic arm is automatically positioned over the patient (Fig. 2). In this way the puncture direction and depth are spec-



Fig. 2 Automatic placement of the robotic arm and insertion of the microwave applicator by the radiologist

ified by the robot on the basis of the previously determined plan.

After needle positioning, a multi-slice verification CT was performed in every case to ensure correct antenna placement. After ablation, all patients underwent a non-contrast multi-slice CT scan of the liver to detect complications.

Radiation exposure dose

The total dose-length product (total DLP), fluoroscopy DLP, the number of verification scans to check the location of the needle during the intervention and the number of fluoroscopic images were recorded for every microwave ablation session. A k factor of 0.015 mSv/(mGy×cm) was used to convert DLP to effective dose.

Procedural accuracy

Immediately prior to the start of tumor ablation, the Cartesian distance from the active center of the microwave applicator to the tumor center was measured (ACFD, active center final deviation). We used OsiriX (OsiriX 6.5, OsiriX Foundation, Geneva) to create a fusion between the contrast-enhanced CT scan with the best tumor visibility and the needle verification scan. If fluoroscopy was used and no verification scan was available, we used the fluoroscopy images for fusion instead. In some cases, manual position correction was required after robot-assisted needle placement. In these cases, the distance of the active center from the tumor center prior to position correction was documented (ACUD, active center uncorrected deviation).

Complications

Complications were documented and defined according to the standardized grading system of the Society of Interventional Radiology (SIR) [13].

Follow-up

All patients underwent a 6-week follow-up including an MRI with liver-specific contrast agent as well as a three-phase computed tomography scan of the liver. The ablation volume measured in the axial plane and the radiographic adjudication/visual assessment of the complete success of the ablation were analyzed by two experienced radiologists. Long-term follow-up was performed by MRI only if possible (no contraindication and normal short-term follow-up).

Statistical analysis

R 3.02 was used to perform all statistical calculations. A p value of $p < 0.05$ was considered the cut-off point of statistical significance. Normality was verified according to statistical parameters (mean, median, skewness and kurtosis). Paired abnormally distributed data were compared with the Mann–Whitney U test. The chi-squared test was used to test for independence of categorical variables.

Table 2 Baseline lesion aspects

Manual or guided	Manual	Guided	p
	($N = 30$)	($N = 34$)	
Skin-to-tumor depth	57.6 ± 19.2	64.8 ± 23.5	0.190
Tumor long axis	22.8 ± 12.4	19.1 ± 9.0	0.172
Tumor short axis	19.6 ± 10.6	16.9 ± 8.0	0.253
Tumor conspicuity native	9.9 ± 8.4	9.3 ± 14.1	0.824
Tumor conspicuity enhanced	35.8 ± 19.9	23.6 ± 17.3	0.011

Lesion conspicuity denotes the difference in attenuation between tumor and liver parenchyma

Table 3 Deviation of the active center from the tumor center

Manual or guided	Manual	Guided	p
	($N = 30$)	($N = 34$)	
ACUD	3.3 ± 1.6	3.1 ± 2.5	0.772
ACFD	3.3 ± 1.6	1.6 ± 1.3	0.000

The deviation after manual puncture is compared to the deviation after robot-assisted puncture, once before (ACUD, active center uncorrected deviation) and once after manual position correction (ACFD, active center final deviation). Manual position correction was performed after robot-assisted placement in 14 of 34 cases (41.2%)

Results

Tumor characteristics

Baseline lesion aspects are summarized in Table 2.

Procedural accuracy

Under consideration of position correction, the deviation of the active center from the tumor center (ACFD) was significantly smaller in robot-assisted ablation than in manual ablation (Table 3). In contrast, there was no significant difference if manual position correction (ACUD) was not taken into consideration.

Procedural duration

For the robot-assisted method, mean duration from the pre-interventional planning multi-slice CT to the beginning of the ablation was 18.3 min (SD 2.0 min). In the cases, which required manual position correction of the needle under fluoroscopy, there was an extra time add-on of 2.8 min (SD 1.2 min). In primarily manual ablation (under fluoroscopy), mean duration from the pre-interventional planning multi-slice CT to the beginning of the ablation was 21.7 min (SD 4.1 min). The intervention duration under robot assistance was significantly shorter than for manual ablation ($p < 0.001$).

Table 4 Comparison of the radiation dose parameters

Manual or guided	Manual (N = 30)	Guided (N = 34)	p
Total mAs	22609.4 ± 8036.2	18196.8 ± 4802.0	0.012
Total DLP	2880.6 ± 1402.5	2216.4 ± 1057.3	0.035
Verification scans CTDI	14.7 ± 21.6	18.3 ± 4.5	0.387
Verification scans DLP	272.8 ± 355.6	417.6 ± 107.1	0.039
Fluoroscopy DLP	488.6 ± 436.1	40.9 ± 63.4	0.000
Fluoroscopy number of slices	64.3 ± 31.5	10.8 ± 14.8	0.000
Fluoroscopy DLP	908.0 ± 956.4	73.7 ± 114.3	0.000

Radiation dose

The total DLP and the fluoroscopy DLP were significantly lower in robot-assisted ablation than manual ablation (Table 4). The effective dose for the entire intervention was on average 33.2 mSv (SD 15.9 mSv) for robot-assisted ablation compared to 43.2 mSv (SD 21 mSv) for manual ablation ($p = 0.04$). In the fluoroscopic guided group, there was a significant difference in radiation dose between patients with and without a multi-slice CT verification scan to control correct needle placement (DLP 3877.2 vs. 2118.5 mGy×cm, $p = 0.002$).

Ablation success

In the follow-up after 6 weeks, complete ablation without residual tumor was seen in 94.1 % (32 of 34) of robot-assisted ablation cases and in 96.7 % (29 of 30) of manual ablation cases. The difference was not statistically significant ($p = 1$).

Complications

There were no complications in robot-assisted ablation. An infected bilioma that was treated via drainage was diagnosed in a patient with biliodigestive anastomosis 8 days after manual ablation.

Discussion

In the present study, we evaluate robot-assisted percutaneous microwave ablation of malignant liver tumors as an alternative to CT-guided manual ablation using fluoroscopy.

For successful and complete ablation, positioning of the microwave applicator that is as precise as possible is extremely important. In manually guided ablations, it is often challenging to detect the exact tumor location in the fluoroscopy images without contrast media. On the other side, the robot software which allows the fusion of the preinterventional contrast-enhanced planning scan with the final needle verification scan (Fig. 3) points out the exact deviation of the needle to the originally planned needle position (tumor cen-

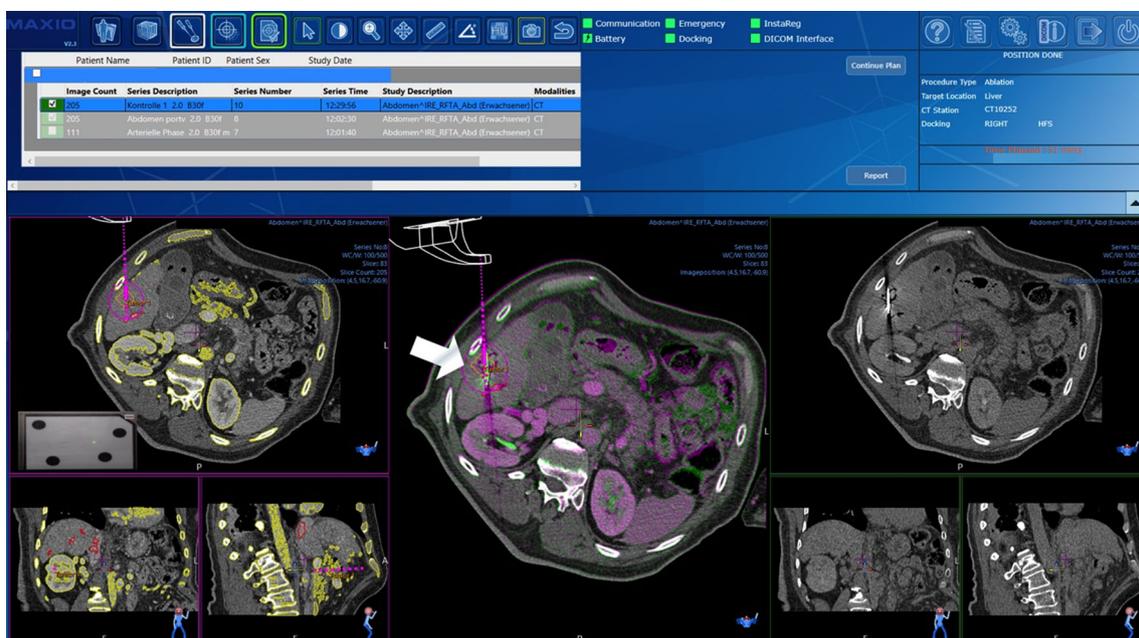


Fig. 3 Image fusion of planning scheme and actual needle position (*white arrow*). The fusion shows an optimum needle position with only minimal caudomedial deviation

ter). Consecutively precise correction of the needle position is possible.

Mbalisike et al. [11] performed a prospective study using 70 patients to evaluate the accuracy of robot-assisted percutaneous microwave ablation of malignant liver tumors. Measuring the distance of the applicator active point to the center of the target tumor after final readjustment they come to a result of a mean deviation of 1.9 mm which is similar to our mean ACFD of 1.3 mm.

It must also be taken into consideration that manual position correction was not necessary in 20 of 34 cases (58.8%). We believe that this is the ideal case for two reasons. On the one hand, it must be assumed that the risk of complications increases with every repositioning of the microwave applicator. On the other hand, the interventionalist is not exposed to radiation.

The effective dose for the entire intervention was on average 33.2 mSv (SD 15.9 mSv) for robot-assisted ablation compared to 43.2 mSv (SD 21 mSv) for manual ablation. The difference was significant ($p = 0.04$). A highly significant difference is seen in the separate analysis of the fluoroscopy DLP (73.7 vs. 908 mGy \times cm, $p < 0.001$). Therefore, patient and interventionalist are subjected to a lower radiation dose in case of robot-assisted tumor ablation.

Although one recent study showed that CTF-guided chest biopsies showed a significantly higher mean CT dose index than MS-CT biopsy mode [14], we believe that in oncological interventions and mostly difficult reachable lesions in the liver it is essential to use CTF for optimal needle placement and to avoid complications. For the same reason in some cases, ultrasound may be a discussable alternative but is not used in clinical routine in our hospital. MRI-guided ablations may play a more important role in the future but are not applied in most hospitals because of the high expenditure.

We think that a combination of MRI and CT is very important for best evaluation of ablation outcome in short-term follow-up (after 6 weeks) in tumor patients with often severe preexisting medical condition. In particular, in these patients MRI images often show artifacts due to respiratory motion and/or ascites, which makes evaluation of tumor recurrence/incomplete ablation difficult. In our opinion further control scans can be performed by MRI only if short-term follow-up is normal.

In the case of robot-assisted ablation, the time-intensive manual procedure involving the microwave applicator in the tumor is eliminated. Instead the robotic arm is positioned automatically and the applicator is placed in apnea in one continuous movement. However, the preparation of the robot, the loading of the images and the planning of the access path require time. Nevertheless we were able to show that the entire intervention duration—from the creation of the CT images to the final needle placement—was faster with robot guidance than in the case of manual puncture alone (18.3

vs. 21.7 min, $p < 0.001$). In contrast, Mbalisike et al. 2014 report an intervention duration that is 3 min longer under robot guidance. However, the difference was not significant.

There was 1 complication in all our cases (manual ablation group). This patient came with a preexisting biliodigestive anastomosis and developed an infected bilioma at the site of ablation 8 days after the intervention. Although there were no difficulties during the ablation procedure, it is a well-known fact that there is a high risk (close to 40–50%) of developing a liver abscess/infected bilioma when thermoablation is performed in patients with a bilioenteric anastomosis [15].

This study has some limitations. The single-center setup and the low number of procedures limit generalization of our results. Another limitation is the retrospective nature of the study. However, we think that within the framework of this study, we could demonstrate the marked reduction in radiation exposure and procedure length.

Conclusion

In summary, it can be stated that in percutaneous thermoablation of malignant liver tumors robot assistance is a fast, reliable and effective alternative to manual CT guidance using fluoroscopy. Robot assistance has the potential to increase precision and reduce radiation dose for the physician and the patient without increasing risk of complications. We would like to state that robot assistance should be thoroughly evaluated for other CT-guided interventions like biopsies or other ablation techniques like RFA or IRE to make the best of this technique and to minimize radiation exposure to patient and physician.

Compliance with ethical standards

Conflict of interest None.

Ethical standard All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent This study was evaluated retrospectively. For this type of study formal consent and institutional review board approval is not required by our hospital.

References

1. Lubner MG, Brace CL, Hinshaw JL, Lee FT Jr (2010) Microwave tumor ablation: mechanism of action, clinical results, and devices. *J Vasc Interv Radiol JVIR* 21(8 Suppl):S192–S203. doi:10.1016/j.jvir.2010.04.007

2. Shibata T, Niinobu T, Ogata N, Takami M (2000) Microwave coagulation therapy for multiple hepatic metastases from colorectal carcinoma. *Cancer* 89(2):276–284
3. Tanaka K, Shimada H, Nagano Y, Endo I, Sekido H, Togo S (2006) Outcome after hepatic resection versus combined resection and microwave ablation for multiple bilobar colorectal metastases to the liver. *Surgery* 139(2):263–273. doi:[10.1016/j.surg.2005.07.036](https://doi.org/10.1016/j.surg.2005.07.036)
4. Kurumi Y, Tani T, Naka S, Shiomi H, Shimizu T, Abe H, Endo Y, Morikawa S (2007) MR-guided microwave ablation for malignancies. *Int J Clin Oncol* 12(2):85–93. doi:[10.1007/s10147-006-0653-7](https://doi.org/10.1007/s10147-006-0653-7)
5. Kuang M, Lu MD, Xie XY, Xu HX, Mo LQ, Liu GJ, Xu ZF, Zheng YL, Liang JY (2007) Liver cancer: increased microwave delivery to ablation zone with cooled-shaft antenna-experimental and clinical studies. *Radiology* 242(3):914–924. doi:[10.1148/radiol.2423052028](https://doi.org/10.1148/radiol.2423052028)
6. Shimada S, Hirota M, Beppu T, Matsuda T, Hayashi N, Tashima S, Takai E, Yamaguchi K, Inoue K, Ogawa M (1998) Complications and management of microwave coagulation therapy for primary and metastatic liver tumors. *Surg Today* 28(11):1130–1137
7. Kloeckner R, dos Santos DP, Schneider J, Kara L, Dueber C, Pitton MB (2013) Radiation exposure in CT-guided interventions. *Eur J Radiol* 82(12):2253–2257. doi:[10.1016/j.ejrad.2013.08.035](https://doi.org/10.1016/j.ejrad.2013.08.035)
8. Rathmann N, Haeusler U, Diezler P, Weiss C, Kostrzewa M, Sadick M, Schoenberg SO, Diehl SJ (2014) Evaluation of radiation exposure of medical staff during CT-guided interventions. *J Am Coll Radiol JACR*. doi:[10.1016/j.jacr.2014.04.012](https://doi.org/10.1016/j.jacr.2014.04.012)
9. Kato R, Katada K, Anno H, Suzuki S, Ida Y, Koga S (1996) Radiation dosimetry at CT fluoroscopy: physician's hand dose and development of needle holders. *Radiology* 201(2):576–578. doi:[10.1148/radiology.201.2.8888264](https://doi.org/10.1148/radiology.201.2.8888264)
10. Solomon SB, Patriciu A, Bohlman ME, Kavoussi LR, Stoianovici D (2002) Robotically driven interventions: a method of using CT fluoroscopy without radiation exposure to the physician. *Radiology* 225(1):277–282. doi:[10.1148/radiol.2251011133](https://doi.org/10.1148/radiol.2251011133)
11. Mbalisike EC, Vogl TJ, Zangos S, Eichler K, Balakrishnan P, Paul J (2014) Image-guided microwave thermoablation of hepatic tumours using novel robotic guidance: an early experience. *Eur Radiol*. doi:[10.1007/s00330-014-3398-0](https://doi.org/10.1007/s00330-014-3398-0)
12. Abdullah BJ, Yeong CH, Goh KL, Yoong BK, Ho GF, Yim CC, Kulkarni A (2015) Robotic-assisted thermal ablation of liver tumours. *Eur Radiol* 25(1):246–257. doi:[10.1007/s00330-014-3391-7](https://doi.org/10.1007/s00330-014-3391-7)
13. Omary RA, Bettmann MA, Cardella JF, Bakal CW, Schwartzberg MS, Sacks D, Rholl KS, Meranze SG, Lewis CA (2003) Quality improvement guidelines for the reporting and archiving of interventional radiology procedures. *J Vasc Interv Radiol JVIR* 14(9 Pt 2):S293–S295
14. Prosch H, Stadler A, Schilling M, Burklin S, Eisenhuber E, Schober E, Mostbeck G (2012) CT fluoroscopy-guided vs. multislice CT biopsy mode-guided lung biopsies: accuracy, complications and radiation dose. *Eur J Radiol* 81(5):1029–1033. doi:[10.1016/j.ejrad.2011.01.064](https://doi.org/10.1016/j.ejrad.2011.01.064)
15. Elias D, Di Pietroantonio D, Gachot B, Menegon P, Hakime A, De Baere T (2006) Liver abscess after radiofrequency ablation of tumors in patients with a biliary tract procedure. *Gastroenterol Clin Biol* 30(6–7):823–827