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Research article

Robotic Insertion of Various Ablation Needles Under Computed Tomography Guidance: Accuracy in Animal Experiments☆

Takao Hiraki[a,*], Takayuki Matsuno[b], Tetsushi Kamegawa[c], Toshiyuki Komaki[a], Jun Sakurai[d], Ryutaro Matsuura[e], Takuya Yamaguchi[f], Takanori Sasaki[g], Toshihiro Iguchi[a], Yusuke Matsui[a], Hideo Gobara[h], Susumu Kanazawa[a]

[a] Department of Radiology, Okayama University Medical School, 2-5-1 Shikatacho, Kitaku, Okayama 700-8558, Japan
[b] Graduate School of Natural Science and Technology, Okayama University, 3-1-1 Tsusimanaka, Kitaku, Okayama 700-8530, Japan
[c] Graduate School of Interdisciplinary Science and Engineering in Health Systems, Okayama University, 3-1-1 Tsusimanaka, Kitaku, Okayama 700-8530, Japan
[d] Center for Innovative Clinical Medicine, Okayama University Hospital, 2-5-1 Shikatacho, Kitaku, Okayama 700-8558, Japan
[e] Graduate School of Health Sciences, Okayama University Medical School, 2-5-1 Shikatacho, Kitaku, Okayama 700-8558, Japan
[f] Division of Radiology, Medical Technology Department, Okayama University Hospital, 2-5-1 Shikatacho, Kitaku, Okayama 700-8558, Japan
[g] Collaborative Research Center for OMIC, Okayama University Graduate School of Medicine, Dentistry, and Pharmaceutical Sciences, 2-5-1 Shikatacho, Kitaku, Okayama 700-8558, Japan
[h] Division of Medical Informatics, Okayama University Hospital, 2-5-1 Shikatacho, Kitaku, Okayama 700-8558, Japan

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ABSTRACT

Objective: To evaluate the accuracy of robotic insertion of various ablation needles at various locations under computed tomography (CT) guidance in swine.

Materials and methods: The robot was used for CT-guided insertion of four ablation needles, namely a single internally cooled radiofrequency ablation (RFA) needle (Cool-tip), a multi-tined expandable RFA needle (LeVeen), a cryoablation needle (IceRod), and an internally cooled microwave ablation needle (Emprint). One author remotely operated the robot with the operation interface in order to orient and insert the needles under CT guidance. Five insertions of each type of ablation needle towards 1.0-mm targets in the liver, kidney, lung, and hip muscle were attempted on the plane of an axial CT image in six swine. Accuracy of needle insertion was evaluated as the three-dimensional length between the target centre and needle tip. The accuracy of needle insertion was compared according to the type of needle used and the location using one-way analysis of variance.

Results: The overall mean accuracy of all four needles in all four locations was 2.8 mm. The mean accuracy of insertion of the Cool-tip needle, LeVeen needle, IceRod needle, and Emprint needle was 2.8 mm, 3.1 mm, 2.5 mm, and 2.7 mm, respectively. The mean accuracy of insertion into the liver, kidney, lung, and hip muscle was 2.7 mm, 2.9 mm, 2.9 mm, and 2.5 mm, respectively. There was no significant difference in insertion accuracy among the needles ($P = .38$) or the locations ($P = .53$).

Conclusion: Robotic insertion of various ablation needles under CT guidance was accurate regardless of type of needle or location in swine.

1. Introduction

Percutaneous ablation therapies, including radiofrequency ablation (RFA), microwave ablation, and cryoablation, have an important role in the treatment of several malignancies. However, compared with surgical resection, ablation has a higher risk of local failure. Accurate insertion of the ablation needle into the lesion is a critical determinant of the therapeutic outcome. Robotic technologies have been introduced in the field of computed tomography (CT)-guided intervention [1,2]. Indeed, some robots, including those manufactured by iSYS Medizintechnik GmbH, InnoMotion Drive Systems BV, and Perfint Healthcare Corporation, have already been commercialized [3–14]. However, the tasks that these robots can perform are limited to needle targeting based on pre-procedural imaging data. Therefore, the physician must insert the needle manually along the trajectory pre-planned by the robot. However, given the potential for needle deflection and target movement during insertion, we believe that the ideal method for accurate needle insertion is needle targeting and insertion under real-time

☆ This study was approved by the Institutional Animal Care and Use Committee at our institution.

* Corresponding author.
E-mail address: takaoh@tc4.so-net.ne.jp (T. Hiraki).

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intraprocedural imaging guidance while adjusting the needle orientation as necessary.

The AcuBot enables robotic needle insertion under real-time image guidance [15–19]. Cleary et al. [17] reported that the accuracy of needle insertion using the AcuBot was equivalent to that of manual insertion in 20 cases of spinal block performed under fluoroscopic imaging. Further, in a randomized study of 14 liver RFA procedures performed under CT fluoroscopy, Patriciu et al. [18] demonstrated that needle insertion using the AcuBot required fewer needle adjustments, a shorter procedure time, and a smaller amount of radiation exposure for both physicians and patients when compared with manual insertion. Regrettably, however, the AcuBot has not yet been commercialized. Most recently, XACT Robotics, Ltd (Caesaria, Israel) developed a patient-mounted CT-guided robotic system with five degrees of freedom, which was evaluated in an animal study [20].

Meanwhile, we have been developing another robot to allow needle insertion under real-time CT guidance. A previous study [21] showed that robotic insertion of biopsy introducer needles into phantoms was equivalent in terms of accuracy to manual insertion without radiation exposure to the physician, and was also accurate in animals. However, the accuracy of robotic insertion of ablation needles remains to be evaluated. The aim of this study was to evaluate the accuracy of robotic insertion of various ablation needles at various locations under CT guidance in an animal model.

2. Materials and methods

The animal experiments were approved by the Institutional Animal Care and Use Committee at our institution. We complied with the NIH guidelines for the use of laboratory animals.

2.1. Robotic system

The robotic system (Zerobot; Medicalnet Okayama, Okayama, Japan) used in this study, which is not commercially available, has been described elsewhere [21]. Briefly, the system comprises a robot and an operation interface (Fig. 1), which allows the physician to control the robot remotely. At present, the robot is not allowed to move automatically during targeting and insertion of the needle; this is achieved by designing the access lock system of robot control to realize exclusive access control. The robot's task is to hold, orient, and insert a needle while adjusting as necessary under CT guidance. The robot is mounted on a mobile platform and physically set to the table of a sliding-gantry CT scanner. A plastic needle holder, specifically designed for a given needle (Fig. 2), may be manually attached to the end of a robot arm (Fig. 1). The needle may also be manually attached to the holder (Fig. 2). The robot has six degrees of freedom, each of which may be driven in two speed modes, i.e., fast and slow. The needle may be inserted up to a maximum of 17 cm in one stroke. The remote centre of motion is available for needle orientation, usually defining the needle tip as a pivot point.

2.2. Ablation needles and targets for needle insertion

Four ablation needles were tested: a 17-gauge, 15-cm-long single internally cooled RFA needle (Cool-tip; Covidien, Mansfield, MA); a 17-gauge, 15-cm-long multi-tined expandable RFA needle (LeVeen; Boston Scientific Corporation, IN); a 17-gauge, 17.5-cm-long cryoablation needle (IceRod MRI Angled 90°; Galil Medical Ltd, Yokneam, Israel); and a 13-gauge, 15-cm-long internally cooled microwave ablation needle (Emprint; Covidien). The above-mentioned needles were selected in this study because those are used in our clinical procedures. Before robotic needle insertion, 1.0-mm target tungsten balls (Humanity Inc., Iwata, Japan) were manually placed in the animals via an 18-gauge coaxial needle (Hakko Co., Ltd., Medical Device Division; Chikuma, Japan) under CT guidance.

2.3. Animal experiments

The primary and secondary study endpoints were the accuracy and safety, respectively, of in vivo robotic needle insertion. Five robotic insertions with different trajectories were attempted with each ablation needle at four locations, i.e., the liver, kidney, lung, and hip muscle.

Six male pigs (mean weight, 26.5 kg; range 23.0–29.5 kg) were sedated with intramuscular ketamine combined with medetomidine and midazolam. Intramuscular atropine sulphate was also administered. General anaesthesia was maintained using isoflurane with oxygen delivered through an endotracheal tube. Respiration was controlled using a ventilator. Vital parameters, including pulse, blood pressure, O_2 saturation, end-tidal CO_2, and body temperature, were monitored throughout the procedure.

The animal experiments were performed at Okayama Medical Innovation Center using a sliding-gantry CT scanner with a bore of 72 cm (Eminence STARGATE, Shimadzu Inc., Kyoto, Japan). The CT scanner was not equipped with a CT fluoroscopic system. The robot was set to the CT table and turned on, after which the position of origin was acquired. The animal was positioned on the CT table according to the intended target location (liver, lateral; kidney, prone; lung, prone or lateral; and hip muscle, lateral). The needle was attached to the needle holder. One of the authors (T.H), who has 22 years of experience in CT-guided intervention and has been involved in the development of the robot for 5 years, operated the robot next to the CT console outside the

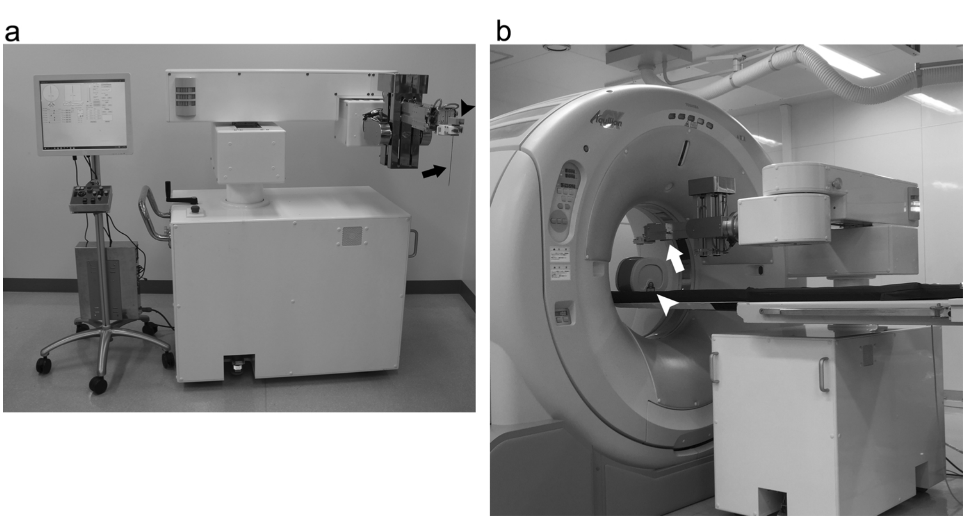

Fig. 1. Photographs of the robot used for the insertion of ablation needles in swine.
(a) The robotic system comprises a robot (right) and an operation interface (left). Attached to the end of the robot arm is the needle holder (arrowhead), to which the ablation needle (arrow) is attached.
(b) The robot is set to the computed tomography (CT) table with its arm (arrow) inside the CT gantry. The arrowhead indicates a phantom.