

MEDICAL INSTRUMENT FOR ROBOTIC ASSISTED RADIOFREQUENCY LIVER ABLATION

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Abstract: *The paper presents the design of a medical instrument proposed for the robotic assisted radio frequency ablation procedure using the PARA-BRACHYROB parallel robotic system. Following the medical procedure requirements, a protocol is established for the robotic assisted radiofrequency liver ablation to serve as design considerations for the medical instrument. The design of the experimental model and its integration on PARA-BRACHYROB are presented.*

Key words: *radiofrequency ablation, medical instrument, parallel robot, design.*

1. Introduction

Percutaneous radiofrequency ablation (RFA) is one of the thermal ablation procedure used in radiation oncology as a treatment method for liver cancer [1, 2, 4, 9]. RFA scope is to heat the tumour in a controlled way, until the liver cancer cells necrosis. One way the clinicians use to achieve RFA of the liver tumours, is with a special needle (containing a set of electrodes) that is inserted through the patient abdomen, within the tumour volume, and is able to deliver an adjustable dose of electromagnetic radiation in the radio spectrum (generated by specialized medical equipment). Limitations of RFA are mainly because of the position inaccuracies of the needle or electrodes [3]. Medical imaging is required in order to overcome the limitations, e.g. the clinician is able to confirm the correct needle placement (before starting the RFA), and the degree of the therapy success (after the RFA is complete). Moreover, robotic assisted needle placement may improve upon the accuracy of the needle and electrode positioning within the tumour (as the robotic system offer more precise motion control than human beings). B.J.J. Abdullah et. al. reported the use of the robotic system ROBIO X [1] and MAXIO [2] for RFA using computerised tomography (CT) for imaging . The robotic system places the needle at the insertion point, but the needle is inserted manually by the clinician. Similarly, B. J. Wood proposed the use of a semi-automated robotic system (with manual needle insertion) with a CT imaging system to improve the RFA procedure [3].

The paper presents the design of a medical instrument that uses a standards commercially available RITA™ RFA needle [12], and is guided by the PARA-

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BRACHYROB parallel robotic system (which is documented as a brachytherapy robot used with CT imaging [7, 8, 10]). The goal is to obtain an automated RFA procedure (i.e. the needle and electrodes are inserted and retracted automatically) with CT guidance. The paper is structured as follows: Section 2 illustrates the RFA medical procedure and defines an automated protocol for the robotic assisted RFA using the insertion instrument; Section 3 presents the design requirements and the experimental model of the instrument together with the PARA-BRACHYROB robotic system; Section 4 presents the conclusions and further work.

2. Robotic Assisted RFA Protocol

In order to establish the design requirements for the medical instrument, a protocol for the robotic assisted percutaneous RFA procedure is defined in close cooperation with the medical staff from University of Medicine and Pharmacy Cluj-Napoca) based on the manually performed RFA described in [4, 9]. The instrument is designed to: use the RITA RFA needle (manually mounted in the instrument support); to be guided by an existing parallel robotic system, PARA-BRACHYROB, which is subject to a patent [6]. The parallel robot has 5 degree of freedom (DOF) with the rotation around the needle longitudinal axis suppressed, and is designed to work with CT imaging [7, 8, 10], but ultrasound imaging is also achievable for RFA using the parallel robot.

The RITA RFA needle [12] is presented in Figure 1, with examples of two different handle actuation levels to illustrate the shape and the volume that the electrodes take (when the electrodes are inserted they take an umbrella like shape). The volume is adjustable to offer flexibility on the tissue ablation procedure, i.e. the electrodes are inserted based on the tumour size (at this stage it is important that the clinician validates the electrodes position).

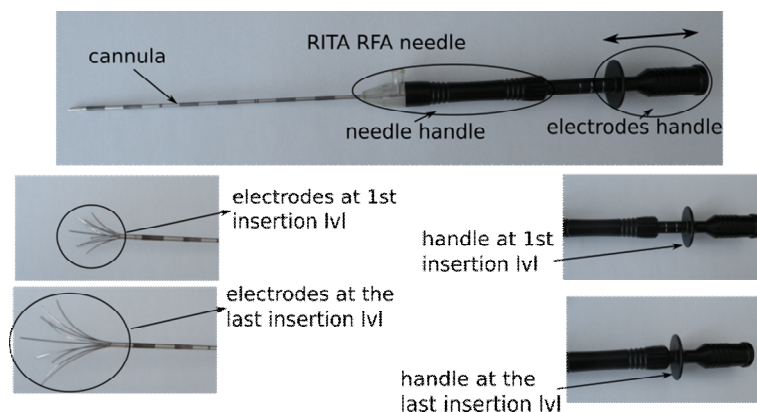


Fig. 1. *RITA RFA needle with different electrodes insertion levels* [7]

The protocol for robotic assisted RFA consists of the following steps (Figure 2):

1. The robot guides the instrument from Homing position to the insertion point; the insertion point is defined by the clinicians after careful analysis of the tumour location (Figure 2.1).
2. The needle is inserted following a linear path to a predefined depth (the target point); the insertion depth is based on the procedure planning (Figure 2.2).

3. The electrodes within the needle are inserted by actuating the needle handle on a linear path until a predefined level (Figure 2.3).
4. The RFA procedure is started by delivering the radiofrequency through the electrodes (Figure 2.4); at this stage the clinician is constantly monitoring the therapy progress.
5. After the therapy is over the electrodes are retracted in the needle (Figure 2.5).
6. The needle is retracted from the patient (Figure 2.6).
7. The robot is sent into Homing position (Figure 2.7) and the needle is dismantled from the instrument (the needles are of one use only).

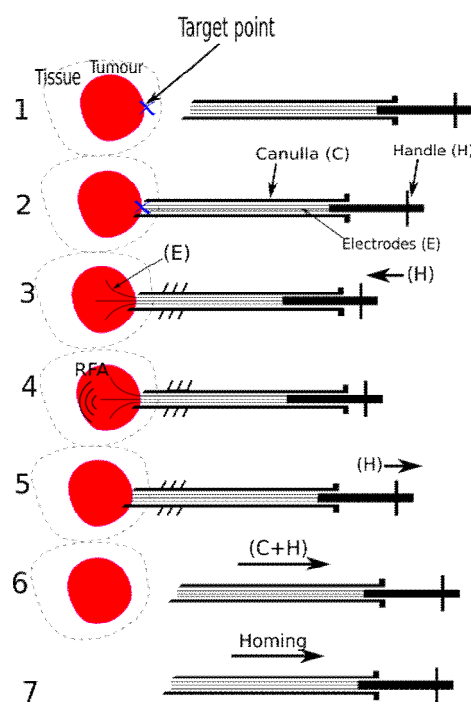


Fig. 2. *Robotic assisted RFA protocol*

3. Design Requirements of the Medical Instrument

Following the protocol defined in the previous section the instrument should have two degrees of freedom, one for needle insertion/retraction and the other for electrodes insertion/retraction. Both the linear actuations have to be precise, with a good resolution, to ensure the precision for reaching the target point in the tissue, and covering the desired volume with the electrodes (based on the tumour size).

Figure 3 illustrates the medical instrument with its components. To achieve the two linear motions of the instrument, a rail (1) was used together with two mounted sledges (2,3) that hold two motion independent handles (one to fix the needle for the needle insertion 4 and the other to fix the needle handle for electrodes insertion 5). The linear motion for the needle insertion is done with a ball screw/nut mechanism (6), where the screw is rotated by a motor (7), and the nut is linearly actuated on the screw rotation axis. The electrode insertion/retraction is also done with a ball screw/nut mechanism (8), actuated by a rotatory

motor (9). A frame that holds both nuts is used, to ensure the motion requirements of the instrument. I.e. with the actuation of motor (7), both sledges (with both handles) are moved, thus obtaining the needle insertion stage, and with the actuation of motor (9) only the sledge (3) is moved for the electrodes insertion retraction stage. To increase precision and decrease the needle bending risk, the needle (10) is held by a needle holder (11) at its tip (the needle slides through the holder at the insertion/retraction stage).

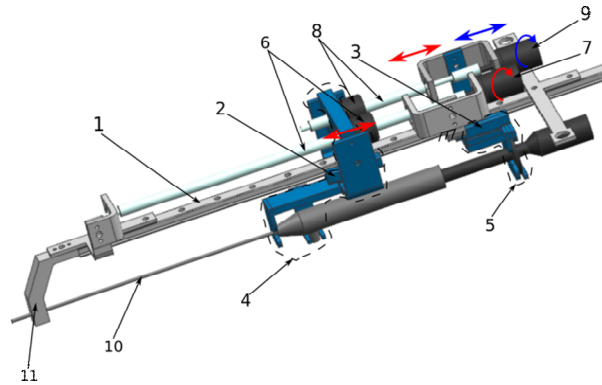


Fig. 3. RFA instrument. CAD representation

The total needle insertion allowed by the instrument is 120 mm (from the total needle length of 140 mm), and the needle handle that actuates the electrodes can be moved for its entire allowed length (45 mm).

The chosen motors for the instrument are from Maxon EG 16 series [13], with an output power of 30 W and a nominal torque (with the chosen gear) of 0.2 Nm. To determine the force output from a torque input in a ball screw/nut mechanism the following relation is used [11]:

$$F = \frac{2\pi \cdot N \cdot T}{Ph}, \quad (1)$$

where F is the output force, Ph is the screw/nut mechanism step, N is the screw/nut mechanism efficiency, and T is the input (motor) torque. In the case of the chosen screw/nut mechanism from SKF, the efficiency is around 0.95. Also, the friction coefficient between the sail and the sledges is 0.03. With screw/nut efficiency close to 1 and a sledge/rail friction close to 0, the majority of the force that the needle needs in the insertion stage is the tissue resistance to needle insertion.

The tissue resistance was experimentally determined with animal tissue (in vitro) using the ZWICK/ROELL testing pressing equipment [14]. The experiment was performed with and without a small skin incision (five trials for each). Figure 4 shows the experimental results, where the needle was inserted 8 sec at a constant speed of 10 mm.sec⁻¹. It is shown that a small skin incision reduces the force required for the insertion stage. This should improve the procedure precision since the needle bending due to resistance should be lower. Using Eq. (1) a resulting torque of around 0.004 Nm is needed to penetrate the tissue which experiments show to give a resistance of maximum 12 N (see Figure 4). With a torque value of 0.2 Nm of the chosen motors the instrument is viable for the RFA procedure.

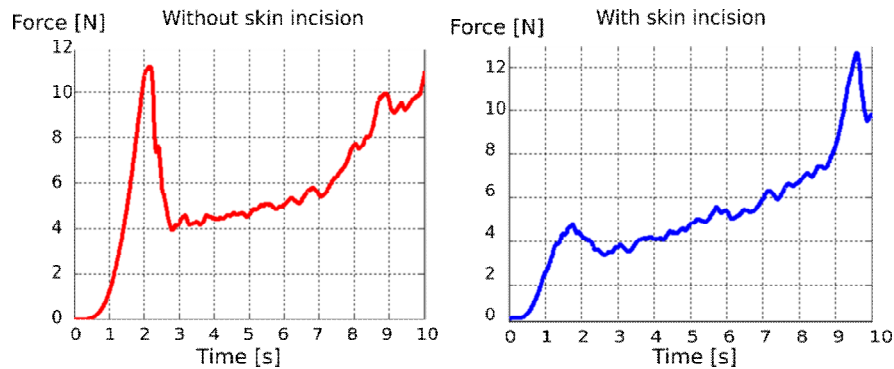


Fig. 4. *Tissue resistance to needle insertion*

4. Experimental Model of Medical Instrument for Ablation

The experimental model of the instrument (subject to a patent [5]) and its integration into PARA-BRACHYROB [7, 8, 10] parallel robotic system is presented in Figure 5. The mechanical part of the medical instrument is complete, and its control is under development.

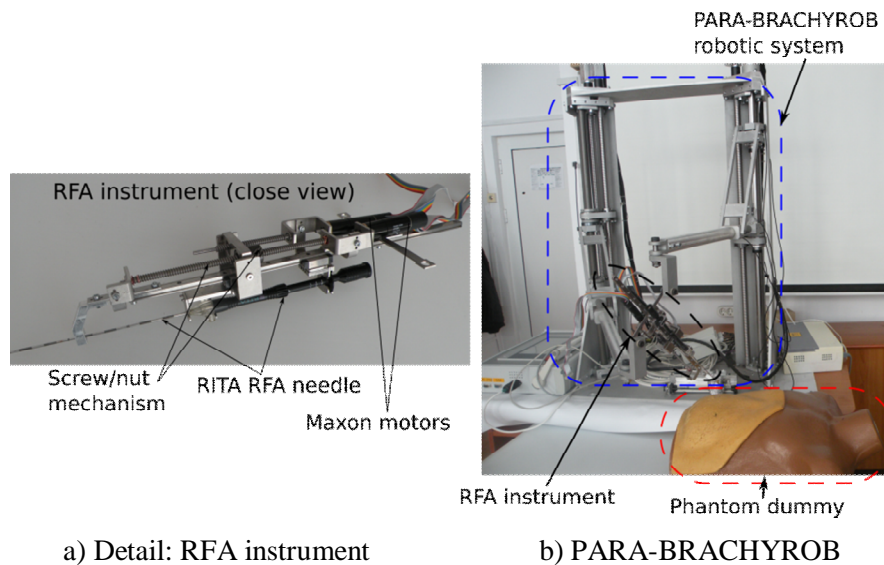


Fig. 5. *Integration of ablation instrument into PARA-BRACHYROB robotic system*

5. Conclusions

A novel medical instrument was presented designed for robotic assisted radiofrequency ablation, which is guided by the PARA-BRACHYROB parallel robotic system. The design requirements have been derived from the medical protocol of the procedure, and the mechanical design was presented having a compact form, with actuation methods that are well suited for the RFA procedure. The novel RFA instrument guided by the parallel robot should offer increase needle position and electrode accuracy.

Further work is intended to fully develop the control system for the parallel robot regarding the robotic RFA procedure, and test the system in phantom dummy experiments in order to validate the system for the medical procedure.

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