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ScienceDirect
Computerized Medical Imaging and Graphics 32 (2008) 611–621
Computerized Medical Imaging and Graphics
www.elsevier.com/locate/compmedimag

Development of a computer assisted system aimed at RFA liver surgery

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Received 24 October 2007; received in revised form 17 June 2008; accepted 8 July 2008

Abstract

Radio frequency ablation (RFA) is a minimally invasive treatment for either hepatocellular carcinoma or metastasis liver carcinoma. In order to resect large lesions, the surgeon has to perform multiple time-consuming destruction cycles and reposition the RFA needle for each of them. The critical step in handling a successful ablation and preventing local recurrence is the correct positioning of the needle. For small tumors, the surgeon places the middle of the active needle tip in the center of the tumor under intra-operative ultrasound guidance. When one application is not enough to cover the entire tumor, the surgeon needs to repeat the treatment after repositioning of the needle, but US guidance is obstructed by the opacity stemming from the first RFA application. In this case the surgeon can only rely on anatomical knowledge and the repositioning of the RFA needle becomes a subjective task limiting the treatment accuracy. We have developed a computer assisted surgery guidance application for this repositioning procedure. Our software application handles the complete process from preoperative image analysis to tool tracking in the operating room. Our framework is mostly used for this RFA procedure, but is also suitable for any other medical or surgery application.

Keywords: Computer assisted surgery; Surgical tool tracking; Liver tumors; Radio frequency ablation; Segmentation; Registration

1. Introduction

Computer assisted procedures are more and more present in contemporary surgery.

The applications in surgical environment cover several aspects: planning of the operation, simulation of some procedure, computer guidance or post-processing of the images in order to evaluate or validate the clinical outcome of the medical procedure.

Our project started from a specific surgeon's request: computer guidance of radio frequency ablation (RFA) instrument aiming at decreasing the local recurrence rate in liver tumors treatment.

RFA is a minimally invasive treatment for either hepatocellular carcinoma (HCC) or metastasis liver carcinoma (MLC) [1,2].

RFA (see Fig. 1), similarly to cryogenization or microwave ablation, allows the surgeon to locally destroy tumors using eventually a percutaneous approach. RFA is a good alternative for treatment of unresectable hepatic malignancies. In most RFA procedures, the surgeon introduces a specific needle-like probe inside the target lesion and applies the RFA process which denaturize the cells with ionic agitation.

In order to resect large lesions, the surgeon has to perform multiple time-consuming destruction cycles and has to reposition the RFA needle for each of them.

The critical step in performing a successful ablation and preventing local recurrence is the correct positioning of the needle. For small tumors (i.e., when a single application allows to destroy the entire tumor and a security margin), the surgeon positions the middle of the active needle tip in the center of the tumor under intra-operative ultrasound (US) guidance (see Fig. 2). When more than one destruction is necessary, US guidance is obstructed by the opacity stemming from the first RFA application. In this case the surgeon can only rely on anatomical knowledge and repositioning the RFA needle becomes a subjective task limiting the treatment accuracy.

In order to ensure an optimal coverage of the tumoral tissue ablation, we propose to optimize the RFA application procedure through computer assisted guidance of the surgeon.

In this new approach, the RFA needle is optically tracked and positioned by the surgeon under US guidance at the center of the lesion. From this point, our system will guide the surgeon for subsequent needle insertions in order to ensure accurate and

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doi:10.1016/j.compmedimag.2008.07.005

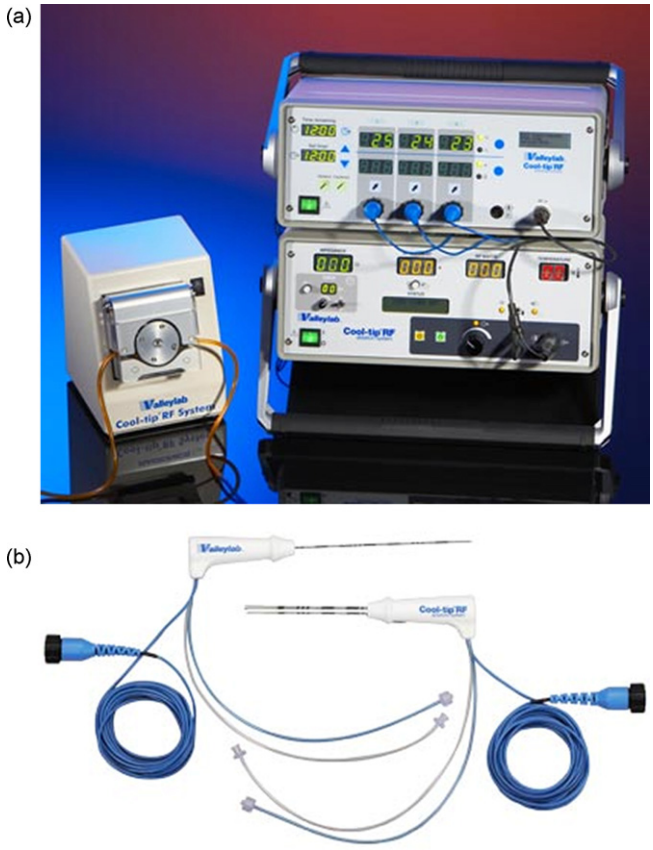

Fig. 1. Radiofrequency generator (a) and needles (b) from Tyco: simple needle and cluster needle (for greater destructions but less movement freedom).

optimal placement of RFA targets, using a 3D virtual visualization of the environment (i.e., the patient's liver and tumors and the tracked needle).

In terms of software requirements, such an application should provide different sets of features: input–output (I/O) management (images or 3D models import and export), image segmentation, image registration, 3D reconstruction of anatomical volumes and surgical instrument position tracking.

2. State-of-the-art

The development of computer assisted surgery has mostly started in neurosurgical [3–12] and orthopedic [13–23] applications, and is often associated to minimally invasive interventions.

The rigid structure of the bones and the encapsulation of the brain in the skull are characteristics which introduce some constraints and facilitate the procedures.

But the interest in modeling soft tissues has grown and other image- or computer-guided applications dedicated to minimally invasive interventions have appeared.

For instance, the brain-shift impact in neurosurgery can be evaluated and taken into account by the registration between preoperative and intra-operative informations [24–26].

More recently, low-field interventional MRI are used to update preoperative images and now widely used in neurosurgery [27–33].

In the cancer treatment of the lung, computed tomographic (CT) fluoroscopy can be used for the RFA needle placement guidance [34].

The needle guidance using ultrasounds images was first described in 1972 [35], and has two considerable advantages

Fig. 2. Surgeon using ultrasound imagery for the RFA needle placement.