HOW DO INTERVENTIONISTS NAVIGATE TO THE TUMOUR?

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During percutaneous radiofrequency ablation of tumours in liver, interventionists place a needle with an electrode into the abdomen and directly in the tumour. This paper focuses on placement and insertion of the needle, two main tasks within this minimally invasive therapy that are currently executed image guided. The paper describes how US- and CT-technology is currently used. Navigation behaviour and situational awareness of the interventionist are explored. Important and reliable information to support accurate orientation and navigation, to support control of motor actions are described.

Image guided intervention, Wayfinding, Situational awareness, Radio frequency ablation, Needle placement

1 Introduction

Minimally Invasive Therapy (MIT) is one of the most important trends in modern medicine. It is performed through one or several small incisions, using specialized medical instruments such as needles, catheters, endoscopic video and robotic tools. MITs for liver tumours are e.g. radiofrequency ablation, laser ablation, cryoablation and ethanol ablation (Dodd III et al 2000) as well as laparoscopic liver resection. Percutaneous radiofrequency ablation of liver tumours (RFA procedure) was developed in the early 1990s (McGahan & van Raalte 2005) and is now a well accepted and widely used MIT to treat tumours in the liver. In this procedure the surgeon or intervention radiologist (both will be called interventionist or user) punctures a needle with an electrode (RFA device) through the skin, into the abdomen, into the liver and hits a predefined place in the tumour. After the needle is placed in the tumour, the electrode in the needle is set to dissipate radio-frequency waves and heats up and coagulates the tissue in the neighbourhood of the electrode. That means that the tumour is locally destroyed by radiofrequency waves dissipating from the electrode.

Poon and colleges (2004) report a significant learning curve in their first 100 RFA procedures, although the direct percutaneous approach with local destruction of the tumour is widely seen as a simple and effective way. The accuracy of the needle placement is seen as an important factor for a successful ablation. It might be also one of the reasons for the reported training effect.

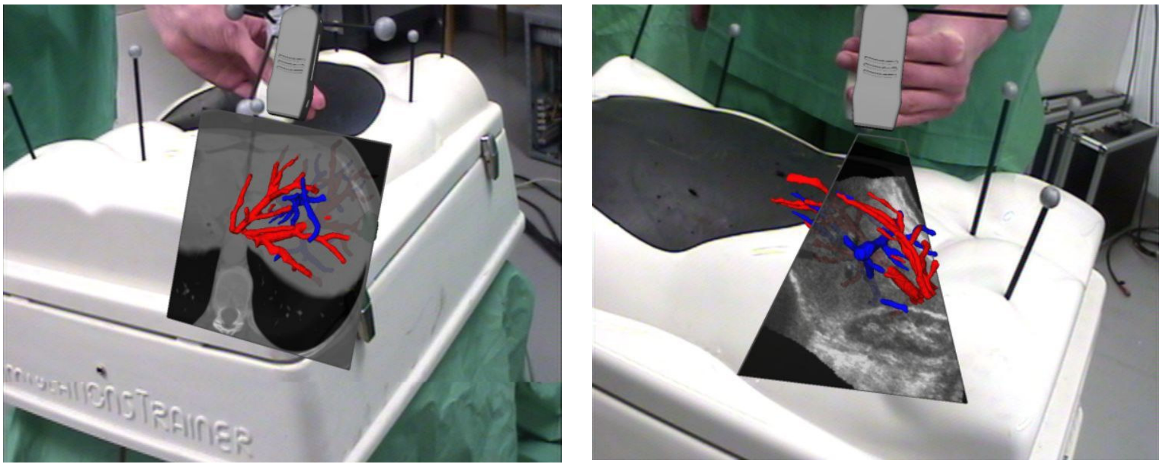
Advances in medical imaging only made the RFA possible; different modalities are used during diagnostic, pre-operative, intra-operative and check-up phase of the procedure. Placement and insertion of the needle into the tumour (intra-operative phase) is executed image guided. For this guidance Computer Tomography (CT), Ultra-Sonography (US) technology and Magnetic Resonance Imaging (MRI) are currently used (Decadt & Siriwardena 2004), the first two of them most frequently. In the last time efforts are made to integrate other image modalities used in the diagnostic phase (e.g. PET, Positron Emission Tomography) into the intervention.

US images are displayed in real-time (30Hz), and are therefore widely used in the intra-operative stage for planning, placement of the needle and control of the action. However edge sharpness, contrast, and spatial resolution are generally low and the detection of certain structures and tumours is not always an easy task. An enhanced image quality of the US image can be achieved for a certain time by delivery of US contrast agents. CT is an X-ray technology and is characterised with high spatial, but low temporal resolution. As the recording of CT images takes some seconds and interventionist tend to use CT economically to keep the X-ray load of the patient low, movements can not be followed. For these reasons a “stop-and-go-tactic” has to be applied when only CT is used for intra-operative guidance. CT is widely used to check actual position of needle and tumour as a security check before the ablation starts. Despite the difficulty and complexity of the task, some interventionists perform the needle insertion just with the help of CT “in the blind”. Best result can be expected when both modalities – US and CT – are used intra-operatively. Most often the different strengths of both modalities are availed by parallel use (e.g. US for real- time guidance and CT for checking actual placement). This might change soon, as at this moment different research groups (with different approaches) aim to combine these two image modalities. The RFA procedure of the future will be supported by medical Mixed Reality Systems (MRS) that combines those modalities in real-time. There is a multiplicity of interlinked technical, medical and ergonomical challenges for the development of such computer systems.

The European research training network ARIS*ER - “Augmented Reality in Surgery” (Freudenthal et al. 2005) aims to support interventionists with “super vision” (e.g. combined US-CT) and “super sense” (e.g. haptic support for the needle insertion). A result of the first design loop 2005-2006 is a prototyped augmented reality system running on a liver phantom (Figures 1 & 2) that supports the interventionist with the newest technological possibilities as wished by many of them (McGahan & van Raalte 2005, Dodd III et al 2000). The prototype presents the two most widely used image modalities and combines strengths of US- and CT-technology. Actual work within the second design loop (Stüdeli et al 2007a&b) focuses i.e. on the refinement of the medical workflow and the design of User Interfaces (UIs). We aim to design a system for intra-operative use with easy-to-use access to preoperative CT/MRI data. We also aim to keep user’s workload as low as possible, and to create an error friendly system.

2 Objectives

This work presents first preliminary results within the second design loop of the ARIS*ER RFA system. The research focused on the use of US- and CT-technology in current RFA procedures with a view into future possibilities. It describes two exemplary user behaviours (user-medical imaging interactions) that aim for a safe and accurate ablation in an efficient way. Investigations and analysis are ongoing; the presented results do not (yet) touch the aspects of future medical Mixed Reality Systems (MRS). But our aim is to gain input for the design of a new system, in particular the design of the UIs, such as navigational aids and control tools.



Figures 1 & 2: Phantom with prototype of the ARIS*ER RFA system (Kalkofen et al 2007). The hand of the user holds the RFA device (tracked US probe and needle) and hereby controls the display window. The cutting plain is displayed in real-time and virtual information can be added. Here, the hepatic vessel tree is overlaid in red and blue colour. The vessel tree is segmented out of pre-operative CT data. **1** (**left**) shows CT data displayed in real-time. **2** (**right**) shows real-time US data with corresponding segmented vessel tree.

3 Methods

Up to now, two interviews with a surgeon and an intervention radiologist, who both are very experienced with RFA, have been performed. Both experts in most cases do not use more than a simple needle holder (RFA device) to support the placement of the needle (manual tasks).

The interviews consisted of three parts: The focus of part one and two was on the current usage of US and/or CT technology during placement and insertion of RFA probe. In part three the view was extended into new technological possibilities and solutions (Stüdeli et al 2007a&b).

1.) The subjects were generally asked about the procedure, how it is organized within the hospital, and who else is involved in the different tasks.

2.) The subjects had to rate different tasks within RFA procedure concerning patient's safety, their own workload, and information gap (Endsley 2000).

3.) A video with the different functionalities of the ARIS*ER RFA prototype in use was shown. It covered the phases: pre-operative data exploration, intra-operative use (Figure 1&2), post-operative data exploration. In the intra-operative part, design ideas for navigational aids were presented (needle extension, rubber band, magic lenses). The subjects were asked to comment and video presentation was stopped as soon as needed. With the help of the video, a structured cognitive walkthrough could be conducted. The subjects and the HF specialists mentally simulated RFA procedure, and the interventionist had the possibility of giving direct feedback as potential future user.

The interviews were analysed on user-medical imaging interaction and the results were compared with cognitive models of navigation and wayfinding (Hunt & Waller 1999, Riecke et al 2000) and situation awareness (Endsley 2000).

4 Results

The interventionists report multi-sensorial interaction during the positioning and insertion of the RFA probe. The following common tasks and subtasks were mentioned:

- **Search:** Explore abdomen and liver (sensing environment, orientation)
  - Re-detection of the target tumour(s)
- **Plan:** Placement of the puncture and exploration of the path trajectory of the RFA probe (Spatial orientation, navigation and wayfinding)
  - Re-check the planned puncture (search for the appropriate attack)
  - Prediction of to be affected nearby tissues and structures by the trajectory (risk estimation)
  - Search for the appropriate infeed angle of the RFA probe (orientation)
  - Estimation on depth of needle penetration (depth information)
- **Act:** Action control during insertion of the RFA probe (movement control)
  - Behaviour of tissue structures and during insertion (deformation and movements)
  - Behaviour of liver (respiratory movement, deformation)
- **Check:** Before and during the ablation the exact position of the RFA probe referred to the tumour (accuracy of placement) is checked and secured (action plan if necessary).

The real-time visual guidance is a special aspect of US-guidance. The RFA probe can be followed almost constantly on the US picture during planning and insertion within the US window. As US probe and RFA probe are connected with a special needle holder, the trajectory of the RFA probe can be displayed at any time with a dotted line. This is a significant support for the targeting task. Constant visual feedback also makes haptic information stronger (and vice versa). Movements and actions can be hand-eye coordinated and controlled. Under US-guidance the breathing can be stopped to hold liver movements. With CT guidance there is a high resolution image of the whole abdomen available. It is possible to see also small tumours. The correct placement of the probe can be checked very accurate and still the combination with real-time visual US-guidance is possible. Special targeting skills of the interventionist make it possible that the breathing does not have to be stopped.

In a next step, these tasks and the reported aspects on safety, workload and information gap were compared with the cognitive model of navigation and wayfinding: Spatial orientation and navigation are based on a number of different sources of information and perceived through different sensory modalities. Successful spatial orientation and navigation involve different processes: 1.) sensing the environment, 2.) building up a mental spatial representation, and 3.) using mental spatial representation (e.g. walk, plan the next steps). Humans have generally a good capacity of dealing with reduced sensorial input and are capable to maintain spatial orientation. The information of the environment does not need to come from the normal sensory systems. We can even build up a mental spatial representation (mental model about space) from artificial representations, such as maps and texts (Hunt and Waller 1999, Riecke et al 2000).

The interventionist creates in the pre-operative stage with the help of CT/MRI images a mental model of the liver (map), the tumour(s) (address) as well as orientation and navigation strategies for safe and efficient needle insertions (route, needle trajectory). The mental model is then used in the intra-operative stage where the interventionist constantly updates his mental map (orientation and navigation) and the intervention plan (action). Anticipation in the pre-operative planning is done, how the intra-operative orientation tasks can be solved with a different image modality (What will I possibly be able to see on the US?). During orientation tasks landmarks and control points are used. Landmarks or familiar regions are areas with special characteristics such as tissue structures or cysts that can be easily recognized (feeling home). Control points are characteristics that help to determine directions. For the trajectory planning different structures are used as control points. In the first phase (place of puncture) interventionist tend to use structures between skin and the liver, such as ribs and edge of lungs. In the second phase structures in the liver such as hepatic ligaments, vessels, and bile duct. During spatial orientation tasks with US, the RFA probe has to be aligned or positioned on the body surface with respect to the planned trajectory (direction) or other references such as the mentioned control points (reference system).

5 Discussion

This first analysis of the intra-operative use of US- and CT-technology with two experienced interventionists shows, that actual tasks of the interventionist are multi-sensorial and demanding tasks in different ways, cognitively as well as physically.

The presented findings can form the basis of further experimental evaluation of the ARIS*ER RFA system. In the future, interesting ergonomical challenges will have to be treated in addition. The usability of the system will only be sufficient when data and navigation aids of the MRS are congruent (Milgram & Colquhoun 1999), and when the viewpoint of the virtual information is optimized to the need of the user (Wang & Milgram 2003). The performed structured cognitive walkthrough with the help of phantom videos combines two goals: to evaluate design ideas (navigation aids, not covered in this paper) and to get insight into current work and problems. This method can, even after only two applications, be stated as fruitful and promising. It was successful in getting a first overview. The gathered contextual knowledge will support the design of intuitive information presentation and UI of the system. Future studies will nevertheless also have to include more powerful cognitive task analysis. Cognitive factors have a decisive impact on whether information technology has a positive influence on human performance (Patel & Kaufmann 1998). To strengthen and objectify the actual findings, the following measures are planned: A) Test the actual findings (as hypotheses) and compare with results from experienced and less-experienced interventionists (learning curve), and B) Find out what information exactly on the CT and the US images is “used”. These further studies will be carried out with the ARIS*ER RFA phantom and eye-tracking systems.

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