Thermal Tumor Ablation

Bachelor of Science Thesis

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Contents

Abstract

Thermal ablation as a treatment for tumors has been established continuously over the past years. It offers a complementary treatment to eliminate or shrink tumors in a minimal invasive way with significant lower risk of major complications. Medical imaging device has become indispensable for accomplishing thermal ablation. The first chapter of this thesis gives an overview of image-guided ablation techniques including radiofrequency (RFA), cryotherapy and microwave.

Since thermal ablation is a complex procedure and because of the collaboration of several specialists during the intervention, there is a need for a planning platform which supports the specialists in planning the ablation. Thereby the second chapter discusses the implementation of a thermal ablation software prototype which allows the collaborators to simulate and plan the ablation (RFA and cryotherapy) before the actual intervention on basis of the patient's specific anatomy.

Zusammenfassung

Hier die deutsche Zusammenfassung einfgen

Acknowledgements

Your acknowledgements to...

Introduction

Chapter 1

Image-guided Thermal Ablation Techniques

1.1 Introduction

1.1.1 Overview

Depending on the modalities, different ablation technologies are used in clinical environment. This chapter compares the different thermal ablative techniques in tumor therapy that are commonly used.
Although the rapid advancement in ablative technique has taken place within the past 20 years, experiments with (RF) ablation of tissues was already documented at the end of the 19th century [FGC05].

What these ablative techniques have in common is, they attempt to kill every viable malignant cell within the designated area by doing minimal damage to the surrounding organs using thermal energy sources in a minimally invasive manner. There are several ways to accomplish this, but they can generally divided into two groups, based on whether heating or freezing is utilized to kill tumor cells [AG05]. The most common one right now is the Radiofrequency Ablation technique, but other technologies are coming more and more to use. Cryoablation is used effectively in the treatment of prostate and kidney. Other thermal energy sources are Laser, High-intensity Focused Ultrasound and Microwave. Especially the latter has shown high potential in treating pulmonary tumors due to the significant larger ablation zone compared with RF [CLB09].

Chemical Ablation was documented being efficient in destroying hepatocellular carcinoma (HCC). Thereby chemical ablative substances (e.g. ethanol or acetic acid) are injected into the tumor. These techniques are not topic of this thesis [AG05].

1.1.2 Image Guidance and Minimal Invasiveness

Tumor ablation represent the non-surgical alternative solution for patient with cancer. Especially with the rapidly increasing advancement in imaging technologies, the techniques become less and less invasive. Even during an intraoperative procedure imaging techniques, such as intraoperative ultrasound (IOUS), are necessary. Thus imaging is essential during the ablation process because the interventional radiologist needs to target the tumor inside the patients body without seeing it (due to minimal invasiveness).

1.1.3 Advantages of Thermal Ablation

Many advantages of ablative therapies exist when compared to surgical resection.

- Alternative to surgery. Patients who are not surgical candidates or Patients with few small Tumors are qualified for thermal ablation.
- Minimal invasiveness. Small probes are punctuated through the skin into the center of the tumor. Due to imaging technologies, there is no need to cut though the skin in most cases.
- Compared to surgery, there is less complications reported during and after the procedure. (Citation needed)
- Re-treatment possible. Especially when metastases reappears.
- Less tissue is removed compared to surgical resection, because only the tumor and a safety margin of 1cm has to be ablated.

1.2 Overview: Thermal Tumor Ablation

Thermal ablative techniques differ mainly by their method of generating heat or cold.

1.2.1 Radiofrequency Ablation

Since the early 1990 there has been enormous development of percutaneous Radiofrequency technology [TKH08]. Radiofrequency Ablation (RFA) as a treatment for primary and secondary hepatic malignancies has been performed successfully for more than 10 years. But there has also been reports for RFA treatment for nearly all kinds of tumors.

Physical Background

In RFA a high-frequency alternating current (typically between 450 - 500 kHz) is applied through an applicator to the tissue. Thereby an electric field within the tissue is established which oscillates with the applied radio frequency inducing ionic friction. When enough energy is deployed over a certain amount of time, the ionic friction results in loss of heat energy, which emerges into the tissue. A coagulative necrosis follows.

The efficacy of the RFA and the resulting size of the coagulation zone depend on the following factors [TKH08]:

- amount of energy deployed
- duration of exposure
- probe design
- tissue-specific factors (heat connectivity and conversion)
- "heat sink" and "oven effect"

Electrodes

As mentioned before, the RF current is deployed an electrode directly into the tissue. In general these electrodes consists of an isolated shaft and an active tip. Figure shows various electrodes pursuing creating different coagulation volume shapes between 2 and 5 cm in diameter.

Radiofrequency Generators

The ablation process is controlled over the generator. Concerning the above mentioned tissue-specific and other factors, the amount and duration of energy exposure has to be well adapted for the tumor. The process is thereby very device-dependent. Thus the personal experience of the operator is essential to ensure efficient treatment of the disease [ea04].

Procedure

RFA is usually performed under conscious sedation. Ultrasound (US), computed tomography (CT) and magnetic resonance imaging (MRI) are normally used for targeting the probe into the tumor and monitoring the result. It usually takes more than one placement, especially when several tumors has to be targeted.

These imaging methods has both advantages and disadvantages. US is mostly used worldwide, because a radiologist is not required for the procedure. CT is used by interventional radiologist the most [TKH08]. It has anatomically exact imaging and is widely available. MRI guidance has high contrast tumor-to-tissue but has the necessity for MR-compatible equipment [Sch10].

RFA is perceived by some clinicians as a simple treatment form, where simply just by inserting a needle and "cooking" the tumor [ea04]. As showed above, the efficacy is dependent on many factors.

Conculusion

Studies has shown Radiofrequency Ablation to be an effective, safe and low-risk technique for treating liver tumors. It has gained more and more popularity over the past years.

RFA is a technology-based treatment form and efficient application is thereby highly dependent on the experience of the operator. Due to the treatment's interdependence on various factors and it's highly conjunction with technology, it can be assumed that a planning phase is necessary.

1.2.2 Cryoablation

The destruction of tissue by freezing is one of the oldest methods of tissue destruction known to mankind [ea05]. But substantial progress in destroying cancer tissue has been made not until recently. In the 60s, nitrogen-cooled probes for cryotherapy established in hepatic surgery. Probes were relatively large in size and open surgical was necessary for the placement of the probe [**?**].. The development of smaller percutaneous cryoprobes, using argon gas eliminated the risks associated with open surgery [AG05]. Currently Cryoablation (CA) is been successfully used to treat several types of tumor.

Physical Background

In order to treat effectively and have control over the process the operator has to understand the mechanisms of cryogenic injury. In recent years freezing has not only used to destroy tissue, but also to preserve. The cell destruction with freezing is achieved by two major mechanisms. Cells are injured by ice crystal formation and the microcirculary failure occurs in the thawing period [GB98]. At low freezing rates, the freezing propagates through the extra-cellular space, which causes water to be drawn from the cell and cell results in osmotic dehydration [AG05]. At faster freezing rates, intra-cellular ice crystal formation causes lethal damages to organelles and membrane [AG05].

Devices

As mentioned before, the development of argon-based systems replaced liquid nitrogen units, because argon has major advantages to nitrogen. As an example, Argon-based systems circulate very fast and as a result, iceball formation emerge very quickly. Probe tips of these systems reach temperatures around -150C.

The two cryoablation systems available in the United States are CRYOcare(TM), EndoCare inc., Irvine, CA and CryoHit(R)(TM), Seed Net(TM), Galil Medical, Wallingford, CT [?]. The latter is the only unit with MRI compatible cryoprobes. They are both argon-based and use simultaneously multiple probes for the placement in the shape of the tumor in order to cover it.

Probes

Both of above mentioned systems use eight sharp-tipped cryoprobes, that can directly place into the tumor. CRYOcare(TM) uses 2.4-4.9mm OD probes and CryoHit(R)(TM) 3.0mm probes.

1.2.3 Microwave Ablation

Microwave Ablation (MWA), the latest development in tumor ablation, has been shown to have potential advantages over RFA, which is the most extensively applied modality. Zones of ablation are significantly larger and therefore faster treatment time can be achieved, compared to RFA. Yet, there is no approved device for patient treatment within the USA or Europe but in the Asian region there has been developing devices since the early 90s [ABDDPLP08].

Physical Background

In Microwave Ablation tissue heating and resulting cell death is induced by electromagnetic waves in the high-frequency in the GHz order. Microwaves has wavelengths between infrared light and radio waves. Similar to RFA, an microwave antenna is placed into the tumor and emits electromagnetic microwaves into the surrounding tissue. It causes water molecules with an electric dipole moment to align themselves to the alternating electric field induced by microwaves. These oscillations of water molecules inside the cells results in warming. Macromolecules are not effected by microwaves but they are heated by convection nonetheless resulting in coagulation necrosis.

Although water molecules has a resonance frequency of ca. 22,2 GHz, they typically absorb 50%-60% of electromagnetic energy effectively in the range of 1-2 GHz [ABDDPLP08]. Hence newly developed MWA devices work at frequencies below 1 GHz and use several applicators at the same time.

Devices

As mentioned before, MWA devices for patient treatment has only applied in Asia so far. reffig:microtaze (left) shows a japanese MW generator with generating power of 150 W. The chinese device (UMC-I Ultrasound-Guided Microwave Coagulator, Institue 207 Aerospace Industry Company, Beijing, China, and Department of Ultrasound of Chinese PLA General Hospital, Beijing, China) with generating power up to 80 W [MdL01, ABDDPLP08]. Both operates at 2.450 MHz emission frequency.

Figure 1.1: Microtaze (Heiwa, Osaka, Japan) and needle electrodes, [GDDI00]

Electrodes

The japanese system uses electrodes with 1.6 mm in diameter and a 2-cm active tip, the chinese system 1.6 mm with a 2.7-cm tip.

1.2.4 Laser Ablation

1.2.5 Ultrasound

1.2.6 Conclusion

Thermal Ablation Techniques have been developed within the last years as technological advances were made. There is a tight ...

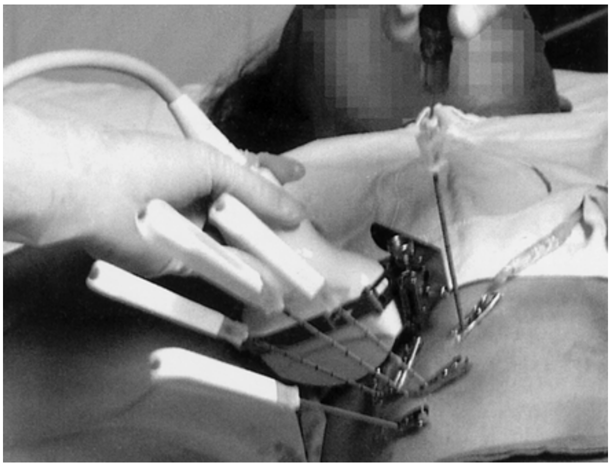

Figure 1.2: "Multiple electrode insertion technique. Five guiding needles are inserted, then microwave energy is applied with one needle at a time." [MdL01]

1.3 Decision Support for Performing Thermal Ablations

1.3.1 Image-guided Procedure

1.3.2 Workflow Description

Chapter 2

Requirement Analysis

2.1 Introduction

Thermal Ablation Techniques are gaining popularity as a complementary choice of therapy for different tumors. Although it is commonly considered a safe and low-risk technique, it still suffers from a noticeable rate of complications. A review showed that complication rate of RFA for liver tumors are higher than previously assumed [**?**]. RFA treatments still has higher tumor recurrence rate than surgical resection. The treatment outcome of an intervention is highly influenced by different factors:

- The placement of the applicator(s) is by far the most time-consuming part of the process. Tumors larger in size or multiple small tumors require repeated applicator placement and ablation. However the accurate placement is essential for the efficient treatment.
- The imaging modalities for the guidance of the applicator placement and monitoring the developing ablation zone. Ultrasound is the most frequently used modality, but it is inadequate for imaging the ablation zone accurately [Sch10]
- Larger tumors require lager ablation zones, but this is accompanied by loss of control with an increased rate of damage to healthy tissue.
- Large vessels adjacent to the tumor are more difficult to ablate completely since the blood flow acts like a heat sink (see heat sink effect).
- Since Thermal Ablation Techniques are technology-based treatments, the outcome is highly dependent on the wide variation of probe devices, imaging modalities and experience of the operator with these technologies.

The accurate estimation of the ablation zone and treatment result is essential for the success of the intervention. Due to the fact that the above mentioned factors has great influence on the outcome of a Thermal Ablation intervention, the thesis focusses on developing a treatment planning system. This system estimates the ablation zone based on the patient-specific anatomy using 3D visualization and virtually place applicators.

Dr. Wolfgang Schramm has reviewed the requirements on such a system in his phd-thesis and therefore the planning software is mostly based on the requirement analysis did by him.

Chapter 3

Planning Software for Supporting the Thermal Ablation Intervention

3.1 Introduction

3.2 Slicer

3.2.1 Introduction

Slicer is a free and open source software platform for medical imaging and visualization distributed under a BSD License. Slicer started as a master thesis in 1998 and since then it was mainly developed by the Surgical Planning Laboratory (SPL), which is part of Harvard Medical School. The current Version is Slicer 4.1 released in April of 2012 and it is cross-platform (Windows 7, Mac OS X, Linux).

The code base of Slicer consists over a million lines of (mostly C++ and Python) code [sli11]. It has many funders (National Institute of Health, National Alliance for Medical Image Computing, Biomedical Informatics Research Network etc.) and partners (Isomics Inc., Kitware Inc. etc.) who enables the ongoing development of Slicer [sli11].

3.2.2 Slicer 4 Architecture

Slicer uses the Model-view-controller (MVC) paradigm for the its architectural design.

- Model: MRML (Medical Reality Markup Language)
  - the XML-based data model of Slicer
  - MRML-nodes describes the scene and application state

- Controller: Logic
  - creates and manages MRML-nodes
  - VTK and ITK
- View: GUI
  - User Interface (Qt)
  - Renderers

One of Slicer's main functionality is its expandability. It is highly flexible and modular and easy to extend its functionality. A large number of toolkits integrated into the architecture, e.g. the Insight Segmentation and Registration Toolkit (ITK) for image processing, the Visualization Toolkit (VTK) for visualization, Qt for the user interface etc.

Python

Python is the language for scripting in Slicer. Slicer's APIs (MRML, Qt, VTK, ITK) are all wrapped. Python has become a very popular scripting language in the past years. But it is more than just a scripting language:

- object-oriented and automatic memory management
- many useful modules included
- widely accepted by the scientific community
- dynamically typed

Qt

Qt (Trolltech, Oslo, Norway) is a C++ library for cross-platform programming of graphical user interfaces (GUI). In Slicer 3, the GUI was KWWidget-based, but it has been ported to Qt since Slicer 4 with the following benefits [**?**]:

- bigger support community since there is a larger number of users and developers
- more training materials available
- design tools (e.g., Qt Designer)
- advanced programming constructs (e.g., signals and slots)
- advanced capabilities (e.g., charting, widgets, SQL interfaces, etc.)
- increased modularity in Slicer

VTK and ITK

The Visualization Toolkit (VTK) can be regarded as the de facto standard for 3D-based visualization in the medical field. It is a freely available C++ library from Kitware, Inc. [?]. For image segmentation and registration Slicer relies on the Insight Toolkit (ITK) [?].

3.2.3 Developing a Scripted Module in Slicer

Slicer offers programmers the possibility to extend its functionality by developing modules. There are 3 types of modules supported by Slicer 4.

- Command Line Interface (CLI)
  The the simplest way to extend Slicer's functionality is by using the command line paradigm. CLIs are typically used to implement algorithms using ITK.

- Loadable Modules
  Loadable Modules are written in C++ and they are compiled outside of the slicer build tree. They have full access of the GUI and Slicer internals and are typically used for computationally intensive tasks.

- Scripted Modules
  Scripted Modules have full access to the Slicer API via Python, since the libraries (Qt, VTK, ITK, MRML etc.) are fully wrapped. It is recommend to use Python for rapid prototyping and therefore the Thermal Ablation Module is programmed as a Scripted Module.

3.3 Results

3.4 Discussion and Outlook

Chapter 4

Conclusio

Put your conclusions and outlooks here

Chapter 5

Terms and abbreviations

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