Engineering precision surgery: Design and implementation of surgical guidance technologies

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CHAPTER 1

GENERAL INTRODUCTION AND OUTLINE OF THIS THESIS

GENERAL INTRODUCTION

Surgery is still one of the main forms of treatment in the management of primary tumors and initial metastatic spread. Accurate surgical resection of cancer-related tissue requires a balance to be struck between radical excision, increasing the chance of a good oncological outcome, and minimal damage to healthy tissues, decreasing the chance of surgery related side effects [1-3]. We and others have reasoned that resection of all diseased tissue while sparring healthy tissue, can be achieved when technologies become available that advance the surgical precision. It is of much importance, both during preoperative diagnosis and intraoperative guidance, that technologies become available that are able to specifically define and localize which tissues are tumor infected and which are not. When tracers are available that can specifically stain the disease-related tissue, a need is created for detection modalities able to carefully localize these tracers. Intraoperatively, such detection modalities can aid tracer localization via a combination of acoustical, numerical or image-based feedback, providing a so-called 'image guided surgery' setup.

Radioactive tracers, also called nuclear tracers, are the clinical standard for molecular imaging due to their sensitivity and high tissue penetration [4]. Radiotracers are used for both preoperative diagnosis and intraoperative radioguidance. Fluorescent tracers offer complementary features such as high resolution, real-time and visual guidance within the surgical field [5]. Unfortunately, tissue attenuation limits the value of fluorescence tracers to superficial indications [6]. Consequently, hybrid tracers, being both radioactive and fluorescent, have been investigated [7, 8]. These tracers provide a best-of-both-worlds scenario for lesion localization. To optimally benefit from these complementary tracer signatures, the development of dedicated hybrid surgical detection modalities has been proposed [9-11]. Surgical navigation takes the concept of image guided surgery even a step further. Analogues to how we use the global positioning system (GPS) based navigation on our smartphones to guide ourselves through traffic in every-day-life, surgical navigation systems specifically guide the surgeon's tool towards the targeted tissue in the patient [12, 13].

In this thesis, the engineering of a number of novel tracing, imaging and navigation modalities is introduced and their potential within image guided surgery has been evaluated.

OUTLINE OF THIS THESIS

Part one of this thesis is focused towards the concept of surgical navigation and investigates the application specifically in combination with fluorescence guided surgery. **Chapter 2** starts off with an introduction in to the general concept of using navigation in the operating room. The first part of this chapter focusses on providing a technical background of the basic concepts needed for a surgical navigation workflow. The second part provides a short overview of the clinical applications, specifically looking at the fields of needle-based interventions, surgical resections and orthopedic surgery.

My research efforts specifically focused on hybrid surgical guidance concepts that make use of both nuclear and fluorescence imaging. In particular, navigation was used to position the fluorescence camera, thereby facilitating the execution of fluorescence guided surgery for applications were lesions are located deep within the patient anatomy. **Chapter 3** introduces the navigation of a fluorescence laparoscope in the robot-assisted surgery setting, a field rapidly emerging for a lot of different surgical indications (e.g. prostatectomy). In **Chapter 4**, the same navigation concept was translated to a fluorescence laparoscope and exoscope, making the hybrid navigation concept applicable to both open surgery (evaluation in penile cancer patients) and laparoscopic surgery (evaluation in prostate cancer patients). From the different proof-of-concept evaluations reported in this thesis and the study by KleinJan et al. [14], it turned out that near-infrared optical tracking, used in the current navigation setup, in some cases obstructed fluorescence imaging. **Chapter 5** investigates this limiting phenomenon in detail, suggesting several engineering solutions that could be used to overcome this obstruction.

Part two introduces the engineering of new (hybrid) detection modalities. **Chapter 6** describes the creation of a preclinical animal imaging modality able to optimally support preclinical hybrid tracer development. **Chapter 7** introduces the concept of freehand Fluorescence imaging, allowing for (pseudo-) 3D imaging and navigation using fluorescent tracer signatures in the operating room. When combined with freehand SPECT this provides a singular hybrid modality, able to benefit from the advantages of nuclear and fluorescence imaging to supply tracer imaging, navigation and augmented reality display. **Chapter 8** specifically focusses on optimizing detection of radioactive tracer signatures during robot-assisted laparoscopic surgery, introducing a tethered and highly flexible DROP-IN gamma probe.

Chapter 9, the future outlook of this thesis, places all the introduced concepts, including surgical navigation, hybrid surgical guidance and DROP-IN modalities, in the perspective of computer-assisted surgery. This chapter provides a review of the recent clinical evaluations in this field, connecting the evaluated technologies and recommending future directions of research. A summary of the thesis is provided in **Chapter 10**.

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