Preface

The future of surgery is intrinsically linked to the future of computational sciences: the medical act will be computer assisted at every single step, from planning to post-surgery recovery and through the surgical procedure itself.

Looking back at the history of surgery, surgery practice has changed dramatically with the extensive use of revolutionary techniques, such as medical imaging, laparoscopy, endoscopy, sensors and actuators, and robots. This trend is dependent on the use of computer processing, computational method, and virtualization.

Computational surgery will not only improve the efficiency and quality of surgery, but will also give new access to very complex operations that require extreme precision and minimum intrusion. Such examples are today's inoperable cancer tumors that have invaded critical tissues or nervous centers. In order for this milestone to be reached quicker and more efficiently, surgeons will have to become very familiar with computing methods, such as image analysis, augmented reality, and/or robotics. It will be critical for surgeons to assimilate computers in their training, understand how computers work, understand the limitations/advantages of these computer tools, and be able to interpret computer imaging and simulations.

The goal of this book is to provide the background on and examples of computational surgery and training in that emerging field. This project started with the workshop "Computational Surgery and Dual Training" that was organized in Strasbourg, France in December 2008, which brought together a group of computer scientists, engineers, and surgeons to discuss interventional procedures and surgeries. The material that follows is organized into five parts which include 17 chapters that take the reader from the day-to-day practice of surgeons to computational optimized surgery methods that are in the making, through disease management, diagnostic, intervention, and the use of modeling and simulation. The last part deals with the fundamental question of training surgeons and how to prepare for the future of surgery while balancing complex objectives, such as cost effectiveness, risk management, and quality of life.

We present first the management of diseases in surgery practice. The domain of surgery is vast and divided into many disciplines from cardiovascular surgery, digestive surgery, neurosurgery, and cancer surgery, involving every system in the human body. We will proceed with representative examples that are well understood by the community for which recent progress in technology has brought changes in clinical management. In breast cancer, for example, significant improvement in survival is attributed to a combination of factors that include improved screening with medical imaging, chemotherapy, radiotherapy, and surgery. However, quality of life depends not only on cancer cure, but satisfaction with the cosmetic results of breast-conserving and reconstruction therapies. We will then present a classic family of problems in endovascular surgery for lower extremity arteries. Endovascular surgery is a relatively new field of surgery that has seen exponential growth with the introduction of minimally invasive procedures, such as endovascular stenting, which have allowed outpatient care. At the same time, there might not be enough insight to carefully assess this new technology. This field of surgery provides a good example of how computational methods, starting from imaging to virtualization through hemodynamic simulation, may improve the decision-making and document efficiency and risk management. However, there is no shortage of computerized information in surgery: doctors acquire large data sets of imaging and all kinds of medical recordings before, during, and after surgery. This overwhelming stream of information can be challenging to synthesize. It is becoming critical indeed to build human computer interfaces that fit the surgeon's needs.

Part I Computer Assisted management of Disease and Surgery is divided into two chapters: Chap. 1 "Breast-Conserving Therapy for Breast Cancer: Targets for Investigation to Improve Results" by Bass and Garbey and Chap. 2 "Changing Paradigms in the Management of Peripheral Vascular Disease – The Need for Integration of Knowledge, Imaging, and Therapeutics" by Davies and Vykoukal.

The work of surgeon does not start in the surgery room and end there. The surgeon must work collaboratively with the radiologist at every step of the diagnostic process.

Medical imaging has been characterized by an explosion of image modalities that combine various forms of ultrasound, X-ray, MRI, PETS, etc… and protocols. It is a difficult exercise to read a medical image and use it for a diagnostic that goes far beyond anatomy. Many images are indirect measurement of metabolic activity or various form of "functioning." Imaging is quite specialized indeed and can come in different forms depending on the organ or simply the scale of interests. Presented are imaging techniques for the brain that have been specifically developed to identify lesion location and extend. Every brain is different indeed so pattern recognition, mapping, and classification, which are natural tools to support the medical decision, are also discussed.

Moving to vascular disease, we will discuss computational methods to identify vessels. These methods are fundamentally related to blood flow visualization. Discussed are imaging analysis techniques for cardiovascular disease and how they can be used by surgeons in their diagnostics. A particular property of blood that is often overlooked is that blood flow carries thermal energy all over the human body. Thermal imaging is a passive sensor that relies heavily on this energy that can be easily detected in vessels proximal to the skin. While the promise of 1980s thermal imaging did not live up to its expectations because of the limitation of equipment and lack of rigor in the exploitation images, there is currently a renewed interest in thermal imaging technology that can be brought to the surgery room. Discussed are some of these developments in the identification of cardiac pulse from a distance, diagnostic tools and their ability to handle qualitative information at the cell level, and image processing. We will also discuss how high-performance computing can perform pattern identification for fast diagnostics.

Part II Image Processing and Diagnostics is divided into five chapters; Chap. 3 “Brain MRI Segmentation” by Bricq et al., Chap. 4 “Knowledge-Driven Recognition and Segmentation of Internal Brain Structures in 3D MRI” by Bloch and material on Cardio including Chap. 5 “New Dimensions in Diagnostic Imaging of the Aorta” by Bismuth et al.; Chap. 6 “Methodological Advances on Pulse Measurement Through Functional Imaging” by Bourlai and Pavlidis, and on cells Chap. 7 “Parallel Multispectral Image Segmentation for Computer Aided Thyroid Cytology” by Shah and Gabriel.

Medical imaging has been used primarily as pre-processing or post-processing steps. Such steps include diagnostic, surgery planning, and recovery assessment. However, minimal invasive surgery cannot proceed without bringing a camera into the instrumentation. Consequently, surgeons end up operating through the eyes of technologic tools: their eyes are not on the patient but instead focus on the display monitor. For instance in the case of abdominal intervention, the surgeon’s hands are extended by laparoscopy tools with less than normal, natural control. Eventually, for zones in the body with difficult access, the surgeon’s hands act on these parts indirectly through the arms of a robot. Computers improve by de facto the way the surgeon works, by relaying their actions through complex computing procedure to reach better accuracy, minimize damage to surrounding tissues, and deliver the right procedure at the right location.

Part III Image Driven Intervention and Robotics describes state of the art procedures in digestive surgery to vascular surgery, MRI guided intervention in surrounding tissues. The discussion begins with Chap. 8 “Computer-Assisted Digestive Surgery” by Soler et al., followed by Chap. 9 “Design of a Robotized Flexible Endoscope for Natural Orifice Transluminal Endoscopic Surgery” by de Mathelin followed by Chap. 10 “MRI-Guided Robot-Assisted Interventions: An Opportunity and a Challenge in Computational Surgery” by Tsekos et al., and concludes with Chap. 11 “Image-Guided Interventions and Robotics” by Bayle et al.

Computational surgery has been a step by step incremental improvement of medical imaging. One starts with the collected image, analyzes it by computational procedures, and runs this process interactively during the course of the surgery. This process provides a new visual tool through dynamic imaging processing that can bring to light information that would otherwise be out of the reach of the surgeon. This in return impacts how the surgeon will practice. Modeling and Simulation have more to do with how things work, and how one can evaluate the effects of surgery. The goal of modeling and simulation in computational surgery is to anticipate based on how the system works. Hemodynamics is more complex than classical fluid dynamics: blood vessels are living organisms with viscoelastic properties that feel the flow and react to it. The time scale involved goes from 1 Hz which is basically the heart beat frequency to dozen of years which is the scale of atherosclerosis build up. Presented is a system biology approach of the vein graft intervention that is a rare example of a practical attempt to integrate multiscale components of a cardiovascular disease into an integrated computational model of the disease. Fundamental mechanisms at the cell level that address the inflammatory process which is key in many diseases will be given to complete the picture. Macroscopic evidence of how fluid dynamic properties relate to hemodynamic diseases with practical clinical cases is given to address the relevance of simulation in endovascular surgery.

A similar approach can be taken when cancer is the diagnosis. We will present a macroscopic model approach for breast cancer that can be patient-specific and addresses some of the clinical issues.

Part IV Modeling, Simulation and Experimental data starts with Chap. 12 "Emerging Mechanisms of Vein Graft Failure: The Dynamic Interaction of Hemodynamics and the Vascular Response to Injury" by Berceli et al., and is followed by Chap. 13 "Modeling and Role of Leukocytes in Inflammation" by Tran-Son-Tay et al. and progresses to Chap. 14 "Multi-Modality Imaging for the Simulation of Cerebral Aneurysm Blood Flow Dynamics" by Karmonik et al., and concludes with Chap. 15 "A Computational Framework for Breast Surgery: Application to Breast-Conserving Therapy" by Thanoon et al.

Computing has infiltrated every step of the surgeon's work, changing the practice to the point that what was learned by a surgeon 15 years ago during formal training has very little to do with practice in the surgery room today. The technological sophistication is evolving so fast that training must adapt as well. To determine what training is needed, a rigorous assessment of the responsibilities and activities of practicing surgeons should be done. Clearly, continuing education and computer simulation will play an important role. Presented here for the first time, is an integrated system that streamlines the work of a surgeon and supports the decision-making process with the use of a standalone computational environment that can also be used for training in computational surgery.

Part V, Training presents Chap. 16 "Simulators in Training" by Dunkin and Chap. 17 "A Computational Desk for Surgeons" by Hilford et al.

Computational surgery is still in its infancy and training in the field is scarce. Although the material presented here on computational surgery is not comprehensive, it nevertheless fills a necessary gap. The goal of this monograph is to provide the necessary background and examples to medical doctors and scientists so that they can speak the same language and communicate more effectively. We hope that, by selecting these different topics, we have provided a tool for training in and a better appreciation of the field of computational surgery. We refer to the Web site of computational surgery.org that will keep this effort growing. Finally, we would like to thank the Partner University Fund (PUF) that supported this team project.

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