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Preface: Detection, Modeling, and Compensation of Organ Motion and Deformation—Part I

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Recent years have seen tremendous advancements in medical imaging technology as well as in image-based diagnostics and image-guided therapeutic procedures. Image acquisition has become fast, very precise, and with great spatial resolution (e.g., CT, MR, ultrasound). Novel approaches for functional or combined functional and anatomical imaging have been developed and found their way into the clinical routine (e.g., SPECT, MR, PET-CT, PET-MR). Consequently, the transformation from film-based to digital radiology has progressed, paving the way for significant technological improvements in therapy approaches, given the fact that all invasive and minimally invasive as well as many noninvasive clinical treatments rely on modern imaging methods. For example, in oncology, a multitude of techniques have emerged as alternatives to surgical resection, such as thermal ablation by radiofrequency (RF), microwave, or high-intensity focused ultrasound (HIFU, FUS) procedures, and during more than four decades, the technological and methodological approaches to radiotherapy have been refined and perfected.

However, while the underlying technology in treatment approaches is improving further, these improvements cannot always be delivered to the patient. Here, a major critical factor is the motion and deformation of organs and target structures as well as of surrounding tissue. In fact, where motion and deformation do not pose a major problem, such as in some neurological imaging and intervention scenarios, most of the technologically feasible precision can also be realized clinically. In areas where motion and deformation are inherent, however, precise image acquisition and therapy is by far not limited by technological constraints, but by a missing motion or deformation compensation of these approaches.

Organ motion and deformation can be tackled from many different directions. Since reducing the organ motion through body fixation, breath holding, or other means is not always possible, image acquisition requires gating, triggering, or adaptive compensation in order to yield motion-insensitive results. This translates to therapeutic approaches, where motion and deformation or organs and tissues often pose an even more critical problem, and gating, triggering, and adaptive compensation are required for a complex interplay between detection and modeling. Modeling refers to biophysical descriptions of whole organs, tissues, or body regions, or to a direct approximation of the relevant motion and deformation. Precise detection of the current deformation state is imperative, and is the basis for either direct compensation or model-based prediction.

In this special issue, we present reviews of the state of the art and critical views on current developments and future challenges from technological and clinical perspectives. In the first part, Ruud van Heeswijk et al. discuss the compensation of motion by the magnetic resonance imaging technique itself. Motion, however, can also be exploited for useful measurements. This is the case in elastography, where, for example, the reaction of tissue to cyclic motion is investigated in order to estimate elasticity parameters. Jonathan Vappou in his paper provides an overview of this technique, both using MRI and ultrasound. Christine Tanner et al. discuss the modeling of organ motion to predict future spatial configurations of the organ. The first part of this special issue is concluded with a paper on the computational aspects of finite element–based modeling of the deformation by Joachim Georgii et al. This paper comes to the conclusion that in principle the simulation of deformation models yields an interactive or real-time performance, even on large meshes when using corotated finite elements, and an implementation on graphics hardware. However,

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incorporating contact handling between different objects and in particular nonlinear material laws will require thorough future research.

In summary, considerable efforts by academia and industry have been invested in detection, modeling, and compensation of motion and deformation in a variety of medical applications. However, many of these approaches face a long and difficult path to clinical translation and the integration into practically useful tools that integrate well with the clinical work flow.