Vascular Imaging

I. Motivation for the Special Issue

ANGIOGRAPHIC imaging is commonly used world-wide for the diagnosis of cardiovascular, cerebrovascular, and peripheral vascular disease. As modern image equipment has developed, angiographic imaging has also come to play a major role in the guidance of interventional procedures. For instance, since 1979 and in the US only, the number of patient catheterizations has increased by 479% to a total of about 1.46 million interventions in 2002 [1].

The field of vascular imaging has progressed rapidly over the last 100 years. These advancements have contributed to improved diagnosis and treatment as well as to a better understanding of vascular diseases. Shortly after the seminal experiments on X-rays by Roentgen, Hascheck, and Lindenthal injected and image the vasculature of an amputated hand using a mixture of salts [2]. Subsequently, femoral and cerebral arteriography using sodium bromide and strontium bromide injections were described in 1924 and 1927 [3]. Since that period, radiopaque contrast angiography has become the gold-standard technique in diagnostic vascular anatomic imaging. Nowadays, there is a range of imaging technologies providing alternative ways to look into the three-dimensional (3-D) anatomy and/or function of the vasculature. Techniques like computed tomography angiography, time-of-flight and phase-contrast magnetic resonance angiography, and duplex and intravascular ultrasonography are now established techniques in several areas of diagnostic vascular imaging [4]–[6]. Over the last few years, advances in contrast media in all angiographic modalities have contributed to a more effective depiction of the vasculature and to safer imaging procedures [7]–[10]. More recently, advances in 3-D rotational angiography [3], multislice computed tomography system [11] and motion-compensation strategies in magnetic resonance angiography [12] have further enabled 3-D visualization in interventional procedures and noninvasive dynamic coronary imaging. Finally, recent developments in molecular imaging allow depicting the expression of indicative marker molecules of the tumor angiogenesis process [13]–[15]. Also, these techniques will provide information with respect to drug treatment monitoring and therapeutic vascular targeting strategies.

Over the last two decades, the substantial parallel developments in advanced image analysis tools have further empowered imaging technologies with artifact reduction, visualization, and quantification capabilities of the vasculature. More recently, imaging manufacturers have become progressively interested in integrating predictive simulation tools in clinical workstations, which will become standard for personalized risk assessment and treatment selection and planning in a few years from now. It is this combination of imaging technology with computational imaging and simulation that will impact the practice of diagnostic imaging, interventional radiology, and surgery in the years to come.

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This special issue is devoted to this exciting field of vascular imaging at the three levels of image acquisition, computational imaging, and computational simulation.

II. Background Statistics

The first call-for-papers of the special issue on vascular imaging was announced in the IEEE Transactions on Medical Imaging issue of October 2003. It was also advertised at several important conferences in the field such as Medical Image Computing and Computer Assisted Interventions 2003, Information Processing in Medical Imaging 2003, IEEE Computers in Cardiology 2003, SPIE Conference on Physiology, Function, and Structure 2004, and the 2004 Annual Meeting of the Society of Cardiovascular Magnetic Resonance. The call received an impressive response with a total of 80 submissions by May 1, 2004. All papers were reviewed by at least three reviewers and many by four experts. A total of 12 papers were accepted and are included in this special issue. Several more submissions are being revised and will be resubmitted for possible inclusion in a later, regular, issue of IEEE Transactions on Medical Imaging.

III. Contents of the Issue

The papers in this special issue can be organized into three main categories. There are two papers about image acquisition or acquisition improvement. Three papers are related to computational simulations in the vascular domain. Finally, seven papers report work on vascular image analysis.

In the area of *image acquisition*, the paper by Niederhauser *et al.* introduces a new imaging system which allows simultaneous acquisition of ultrasound and optoacoustic images. The system exploits the thermoelastic effect by which highly scattering tissue absorbs the energy of short laser pulses subsequently producing a pressure transient that is recorded with a piezoelectric transducer. The authors show impressive spatial resolution of subcutaneous vasculature. Shechter *et al.* present a technique for motion correction of coronary X-ray images. The authors use bi-plane angiography for reconstructing a $3\mathrm{D} + \mathrm{t}$ model of the coronary tree. This model is subsequently used to compute a dewarping function to motion-correct an image at any other viewpoint.

Next, three papers fall within the area of *computational simulation*. In the work by Glor *et al.* the use of image-based computational fluid dynamics (CFD) is investigated to numerically assess wall shear stress in the carotid artery with boundary conditions computed from a sequence of two-dimensional B-mode images of the carotid bifurcation assembled to produce a 3-D volume. Specifically, the authors have looked at the sensitivity of the computed variables to the ultrasound operator, the image analysis steps, and the CFD. They conclude that the variability due to the ultrasound operator is larger than that of the remaining steps. They argue that with some basic operator training the variability may be reduced. Cebral *et al.* present a pipeline for subject-specific image-based computational fluid dynamics of brain aneurysms. The authors studied the sensitivity of the technique to a large number of variables like image segmentation, the modeler, the rheological model, and the flow division. Finally, Cebral and Lohner present a method for modeling hemodynamics across complex endovascular device (very difficult using standard techniques) using a novel adaptive embedding technique. The technique is illustrated in the context of coil and stent simulation in brain aneurysms.

Finally, several papers focus on vascular *image analysis and visualization*. Olabarriaga *et al.* present a method for the segmentation of the lumen and thrombus in abdominal aorta aneurysms using a deformable modeling approach that uses nonparametric statistical information to drive the model deformation. Agam *et al.* employ a correlation-based enhancement filter and fuzzy shape representation to define pulmonary vasculature in order to reduce false positives during automated pulmonary nodule detection. Rhode *et al.* report on two techniques to perform flow measurements from X-ray angiography with superior performance to the classical concentration-distance algorithm. The authors provide experimental evidence that the proposed approaches out-perform the traditional techniques. Baldewsing *et al.* present a technique for estimating the composition of vulnerable plaque from intravascular ultrasound (IVUS) images. To this end, the authors develop a model-based strategy by which they optimize the deformation of a parametric model to match measured deformations using IVUS elastograms. Volkau *et al.* report on a technique to reconstruct high-quality vascular models starting from a segmentation of the vasculature and corresponding skeleton representation. The method carefully takes into account bifurcations and is robust to segmentation errors. The approach is applicable for building reference cerebrovascular atlases, developing applications for simulation and planning of interventional radiology procedures and vascular surgery, and in education. The work of Oeltze and Preim presents a method coined convolution surfaces, which allows efficient visualization of vascular structures with excellent quality. Finally, the short communication by Niemistö *et al.* presents a technique for quantification of *in vivo* angiogenesis. This technique is applied to robust quantification of vascular parameters in co-culturing endothelial cells with fibroblasts for quantifying the influence of anti-angiogenic agents for cancer treatment.

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