Bone-Subtraction CT angiography and segmentation of intracranial aneurysms

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The incidence of subarachnoid haemorrhages (SAH) linked to rupture of an aneurysm is 6 out of a population of 100,000 [Na05]. Prevalence of intracranial aneurysms is estimated to be at least 1.0% of the total population [Br05]. The prognosis of an SAH due to a ruptured aneurysm is poor, about 50% of the patients die immediately [Ki97].

Aneurysm diameter is directly related to the risk of rupture, the age of the patient correlates inversely; a long-term study found a relative risk for rupture of 1.11 per mm in diameter of the unruptured aneurysm [Ju00].

Therapeutic options are surgical aneurysm clipping and endovascular coiling [Ma03], [Ki05].

Given the dramatic consequences of aneurysm rupture standardized imaging approaches for detecting and assessing aneurysms are of major importance. Still many aneurysms are detected by chance in computed tomography angiography (CTA) scans performed for other reasons.

We sought to develop an image post-processing tool for accurate visualization of vascular structures in general and of aneurysms and their adjoining vessels in particular.

CTA has proven to be a powerful, widely available, and non-invasive modality to assess the cerebral vasculature [We07], [To04], [Pa07]. Separation of vessels and bone, especially at the skull base, is still a major challenge in visualizing CTA data [Le06]. Bone subtraction CTA [Le05], [To06], [Ve01] has been developed to overcome this problem. Bone subtraction CTA, also called NeuroDSA in its commercially available version, facilitates a bone-free three-dimensional visualization of the intracranial vessels, supporting a reliable and more standardized screening for aneurysms and other vascular pathology. To generate bone-free CTA images NeuroDSA requires two spiral scans, one (low-dose) non-enhanced (NECT) and one contrast enhanced (CTA) scan. The NECT scan is used to create a 3D bone model, the so-called mask. In the next step all voxels in the mask with a CT value below 80 Hounsfield Units (HU) are considered to represent parenchyma and are set to 0 HU in order to be retained in the final NeuroDSA data. Further 80 HU are deducted from the CT values of the remaining voxels in the mask, which prevents the generation of saltus in the CT values. The next step is to register mask and CTA (registration see below) by way of rigid transformation. Subtraction of the mask from CTA results in NeuroDSA data (Fig. 1), where vascular structures are clearly displayed and parenchyma is conserved [An07], [Op05], [Ve01].

One major challenge of bone subtraction CTA which we address here is that even minuscule movements of the patient lead to motion artefacts. As the skull can be considered to be a rigid structure, motion correction can be performed by rigid registration applying translation and rotation only. Patient movements can also appear during one scan which makes an additional motion correction necessary. Here the entire image is subject to a slabwise motion correction where each single slab of the CTA image is registered to the respective slab of the NECT image. Furthermore isolated movements of bones, for example the jaw or vertebrae, lead to suboptimal registration and bone subtraction and require a different type of motion correction. This is accomplished by a dedicated detection of inaccurate registered bones in the final data set and a re-registration of these bones in up to five steps.

Besides fully automated and accurate suppression of bone in CTA data in order to facilitate aneurysm detection, our tool provides advanced evaluation of aneurysm geometry. Volume and diameter of the aneurysm can be assessed and the fluid dynamics inside the aneurysm can be modelled. A mouse click into the aneurysm on the NeuroDSA image initiates the segmentation process.

The segmentation algorithm implements an adaptive region growing which adjusts to the greyvalues present in the vessels. Starting from the first voxel marked by the user a region is grown as a 3D-6 neighborhood of segmented voxels. Only voxels neighboring voxels segmented in the prior step are added to the region thus ensuring connective growth. The amount of voxels segmented in each growth step provides information about the phase of the segmentation. As the process starts the volume of the aneurysm is filled by the symmetrical octahedral fashion in which the region growing ensues and hence this figure increases with each step. Once the growing reaches walls of the aneurysm the number of newly segmented voxels per step starts to decrease. At the time this number hits a local minimum the aneurysm is fully segmented and the segmentation just touches the associated vessel (Fig. 2). Appropriate termination of the segmentation without any further user interaction and resulting from this an accurate estimation of the volume of the aneurysm was accomplished on all tested data sets (n = 20). From the segmented data maximum and minimum diameters of the aneurysm and the center of center of gravity can be calculated. By executing additional steps of segmentation the adjacent vessels can be segmented in order to visualize the topographic vascular situation in the vicinity of the aneurysm. The segmentation of aneurysm and associated vessels is employed to generate a surface model of these structures which approximates the natural shape of the vascular structures as close a possible. A stereolithography (STL) file, generated by the neighboring cells algorithm, which is related to the marching cubes algorithm, holds the data describing the surface model (Fig. 3). Modeling of the fluid dynamics in the aneurysm is facilitated by these STL files and thus the impact of the bloodstream and forces developing at the vessel wall can be calculated.

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