Determination of in-vivo corrosion rates of degradable implants by SR-microtomography

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In trauma and orthopaedic surgery metal implants are widely used for bone augmentation after bone fracture to provide the fracture site with adequate stabilization to heal. In order to prevent a second operative procedure for implant removal, innovative materials for implants have to be manufactured meeting the requirements for biocompatibility and degradablity while the fracture is healing. Magnesium alloys seems to meet these requirements for degradable biomaterials [1]. For the development of magnesium alloys, that are appropriate for the specific local application in the human organism, the in-vivo corrosion rate has to be measured and the understanding of the corrosion process has to be gained. Both of these aims can be achieved by SR-based microtomography: Within this study the remaining metal implant and the corrosion layer were quantified on the basis of 3D-tomographic datasets of the specimen. Since absorption values in the dataset of the corrosion layer and the remaining metal implant are quite similar, the segmentation of different region of interest (ROI) with 3D data/image processing is still a challenge.
Sample cylinders made of magnesium alloys were implanted into the femur of rabbits and explanted after various time intervals. In the project II-078-001, the specimens were imaged by absorption microtomography utilizing synchrotron radiation. The projection data were aquired at 720 rotation steps equally spaced in the half-circle at beamline W2 using 31 keV photon energy. To obtain a high spatial resolution the specimens were investigated in two different position of the z-axis. Further these two separat datasets were finally stacked to an entire dataset. The voxel size of an unbinned dataset was equal to 10 µm. This voxel size is adequate to detect the corrosion layer of the degrading magnesium implant. In some cases the specimen could be investigated at a higher magnification to obtain better resolution of the corrosion layer.

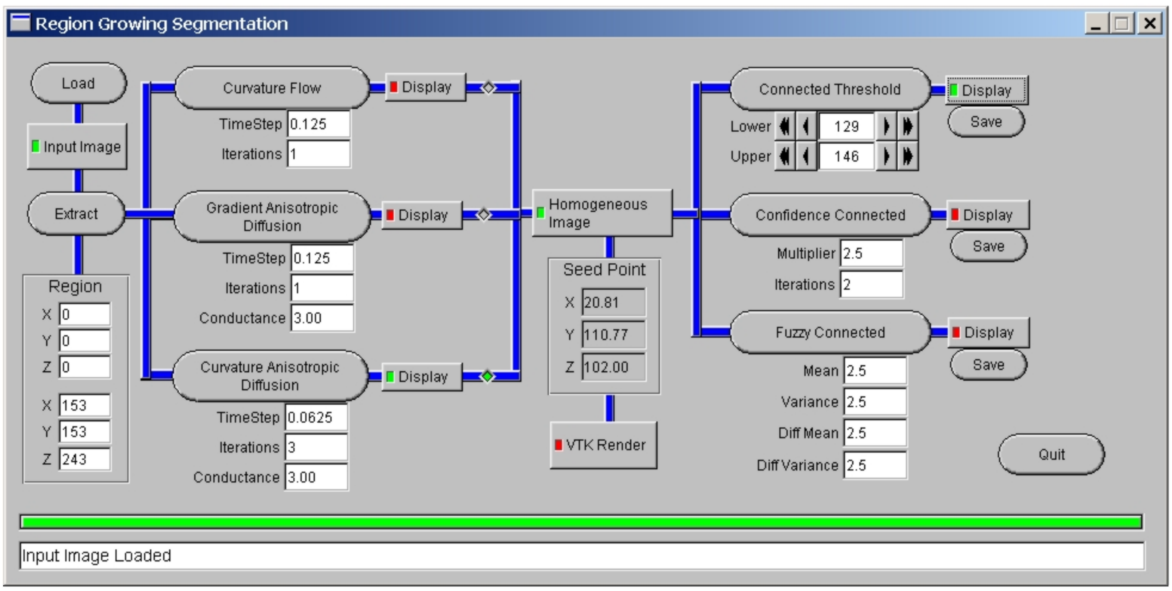

Figure 1: Screenshot of ITK-Tool displaying various filter systems for data pre-processing

For further data processing, the ROI was defined as a reduced cylindrical volume of the entire dataset that enclosed 0.5 mm of surrounding bone of the degrading magnesium implant. Subsequently, the ITK tool "Region Growing Segmentation" was used for further 3D-analysis on the dataset (Fig.1) [2].
The combination of different 3D filter systems shown in figure 1 enabled us to binarize the dataset for segmenting the corrosion layer and to count the corresponding voxel. To minimize the influence of the global threshold on the segmented volume of the corrosion layer, the processing algorithm was set as followed: In a slice of the entire 32-bit floating point dataset an area of voxels representing the corrosion layer was selected. The mean attenuation value of these voxels was calculated. The specimens were imaged by tomography at various magnification, therefore, the size of the voxels were different in many datasets. To standardize the attenuation value per voxel for all datasets, the attenuation value per voxel was adjusted to attenuation value per micrometer. The threshold for the segmented volume of the corrosion layer in each dataset was determined by using an "upper and lower threshold" corresponding to +/- 10 percent of the mean attenuation value per micrometer in the 32-bit float-dataset.
This procedure enabled us to use the corresponding attentuation values in each dataset to determine the corrosion layer in the 8-bit tiff-images calculated from the 32-bit float datasets.
In further research, this technique will allow us to determine in-vivo corrosion rates of various magnesium implants.

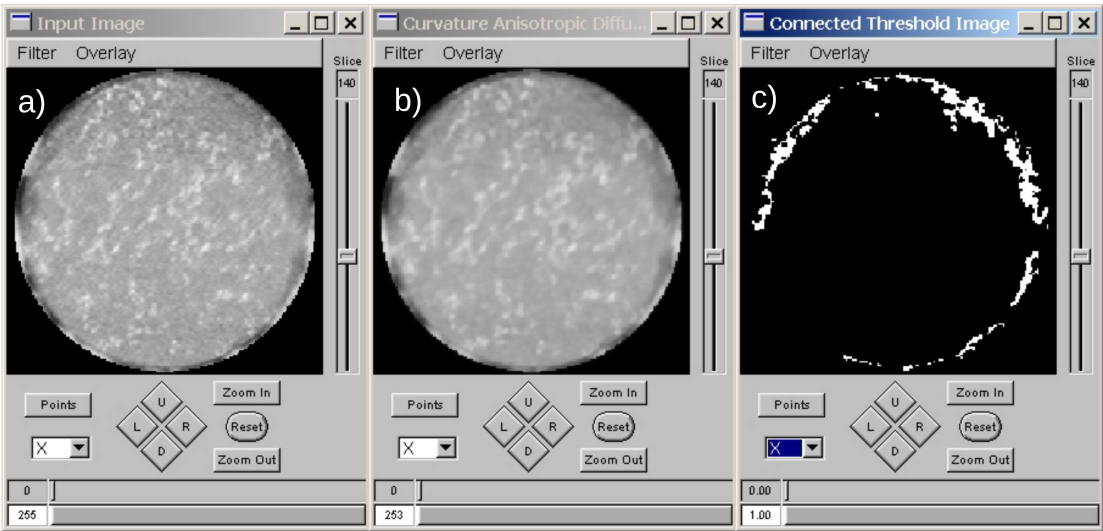

Figure 2: Data processing starting with the original 32-bit dataset (a) followed by using the filter "Curvature Anisotropic Diffusion" (b) and finally binarizing the dataset with the determined threshold (c).

References

[1] F. WITTE ET AL., *In-vivo corrosion of four magnesium alloys and the associated bone response*. Biomaterials, in press

[2] ITK Version 1.6.0 http://www.itk.org

Acknowledgement

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