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Volume Visualization in Magnetic Resonance Angiography

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Visualization of blood vessels for diagnostic and therapeutical purposes is one of the standard procedures in radiological practice. In conventional *angiography*, a contrast agent is injected into a patient's artery or vein, and its distribution is shown on two-dimensional X-ray projections. This method is well-suited for the investigation of a wide variety of disorders, but problems such as X-ray exposure both for the patient and the radiologist and possible complications, e.g. allergic reactions to the contrast agent, make its use questionable in many cases.

Magnetic Resonance Angiography

More recently, a new angiographic technique has been developed which is based on magnetic resonance imaging (MRI). This so-called *magnetic resonance angiography* (MRA) provides stacks of parallel cross-sectional images which show the vessels (more precisely: the flowing blood) as bright spots and lines, surrounded by dark stationary tissue. Fortunately, MRA data can be acquired on standard MRI scanners which are available at many major hospitals. Ruggieri et al. [1] describe this technique in detail. A drawback, however, is based on the fact that vessels never run in a two-dimensional plane. Even for an experienced radiologist, it is thus extremely difficult to get a proper impression of the spatial structures of the vessels only from the cross-sectional images.

Volume Visualization

In order to achieve a more natural presentation of tomographic volume data, *volume visualization* techniques have been developed which provide three-dimensional (3D) views of the organs of interest. These techniques have proven clinically useful in fields such as craniofacial surgery or orthopedics. In our experience, voxel-based methods such as the ray casting algorithm which we use in our VOXEL-MAN visualization system are best suited for interactive exploration of medical volume data, because all information is kept during the rendering process. As shown by Höhne et al. [2], segmentation or visualization parameters can thus easily be changed.

Applied to MRA data, it turns out that aliasing effects which can be largely ignored in visualizing larger objects result in some strong artifacts. The grid for resampling the volume for 3D projection is often chosen to have the same width as the original data. In this case, however, the shape of the vessels appears jagged and the surface normal vectors of small objects (calculated from gray level gradients) do not correspond to reality. Oversampling the data results in an interpolation of both shape and normal vectors, thus producing more natural-looking vessels. Four times oversampling in all three dimensions, which was used for all images shown here unless stated otherwise, seems to be a good compromise between improved image quality and increased calculation times. We are currently investigating deviations from reality as a function of sampling rate and interpolation method, using the methods presented by Tiede et al. [3].

A 3D visualization of blood vessels inside a human head from MRA data is shown in fig. 1. Vessels were defined with a global intensity threshold. The image closely resembles a corrosion preparation in an anatomical atlas. Position, orientation and spatial relations of the vessels are clearly visualized. The large vessels on the left are the sinuses (veins) which drain large parts of the brain. The size of the depicted vessels is limited by the spatial resolution of the MRA data (at the order of 1 mm), so that smaller vessels appear as broken lines.

A decisive advantage of this new angiographic technique is the possibility to show vessels within their anatomical context. The required information is obtained by

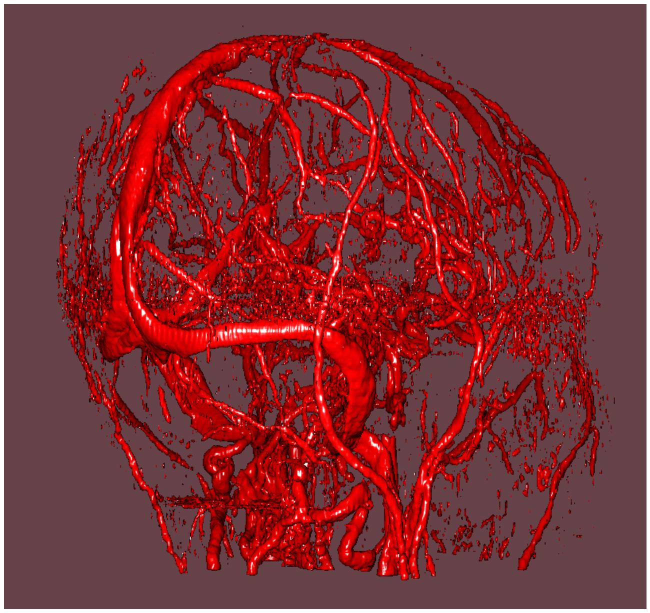

Figure 1: *Three-dimensional display of cranial blood vessels in a right posterior view (in vivo). The image was rendered from an MRA data volume of 256 $\times$ 256 $\times$ 165 voxels, with a spatial resolution of 0.86 mm $\times$ 0.86 mm $\times$ 2.0 mm.*

fusing the MRA with a matched MRI data volume. In fig. 2, structures of the brain, eyes (dark circles on the left), and other organs are shown on cross-sectional images. The course of a blood vessel can thus be studied in relation to the surrounding tissue. Slices may be arbitrarily placed through the MRI volume. Both data sets were taken in one session, with a combined acquisition time of 23 minutes.

Spatial perception is further improved if the vessels are shown in relation to other surfaces. A combined presentation of blood vessels from MRA with brain and skin surface from MRI is shown in fig. 3. Since it may be hazardous to injure a vessel during a surgical intervention, these images are especially useful for finding the best possible access path to a lesion. A scene from an interactive surgical simulation is shown in fig. 4.

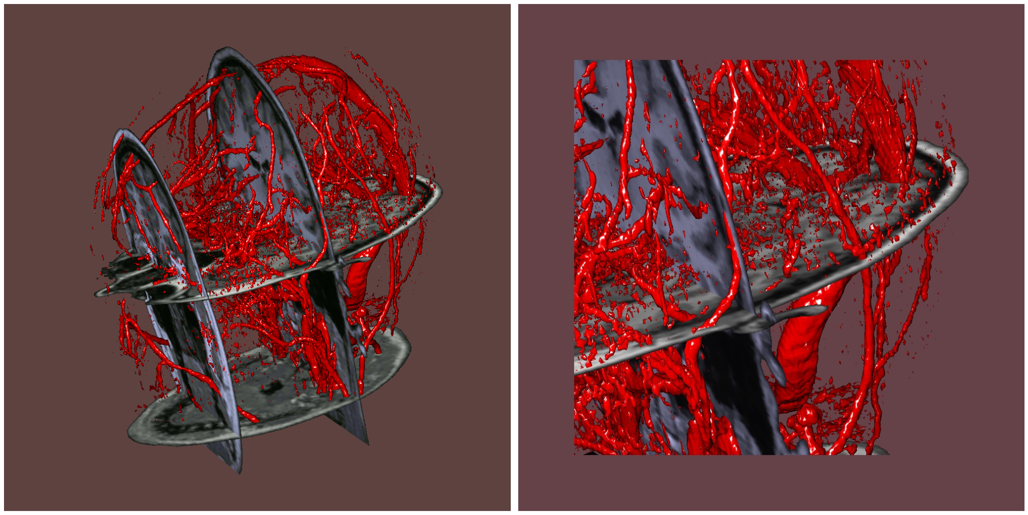

Figure 2: *3D visualization of blood vessels within their anatomical context. Data were obtained from MRA (vessels) and MRI (cross-sectional images). (a): overview, rendered with 4 times oversampling of the original data. (b): detail, rendered with 8 times oversampling. The quality of visualization, especially of very small objects, is thus further improved.*

Conclusions

MRA in connection with volume visualization techniques offers a new, non-invasive technique for the investigation of blood vessels, which is now being introduced into clinical practice. In connection with MRI, the vessels can even be shown in their anatomical context. Application is mainly in surgical planning, where this method provides a true three-dimensional description of the operation site and is thus superior to any other method, and in the diagnosis of diseases which change the blood flow (e.g. angioma). Current limitations are the low spatial resolution of MRA, as compared to conventional angiography, and the rather long acquisition times (approximately 10–20 minutes). Considering the improvements in magnetic resonance imaging technology in recent years, however, further improvements can be expected.

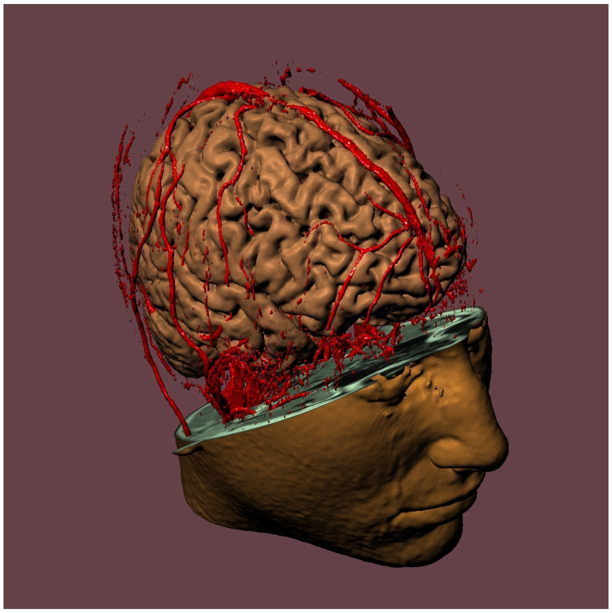

Figure 3: *Blood vessels in relation to skin and brain surface. Data were obtained from MRA (vessels) and MRI (soft tissue).*

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References

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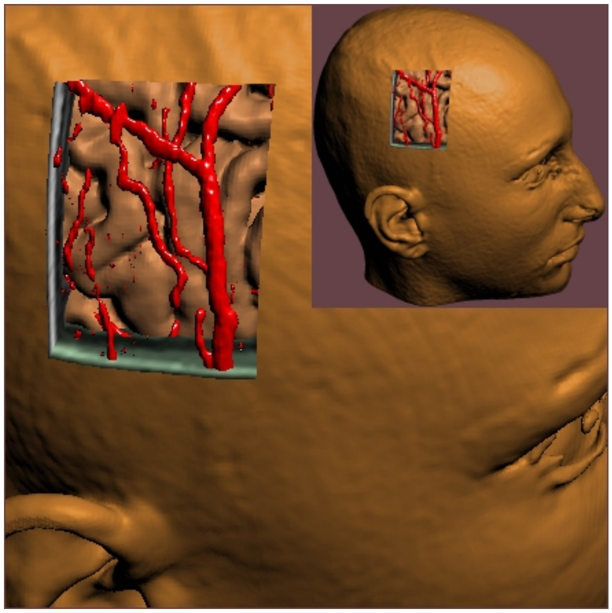

Figure 4: *Interactive investigation of MRI/MRA volume data carried out to find the best possible access path to a lesion. Skin and bone have been partly removed to study the position of some vessels at risk.*

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