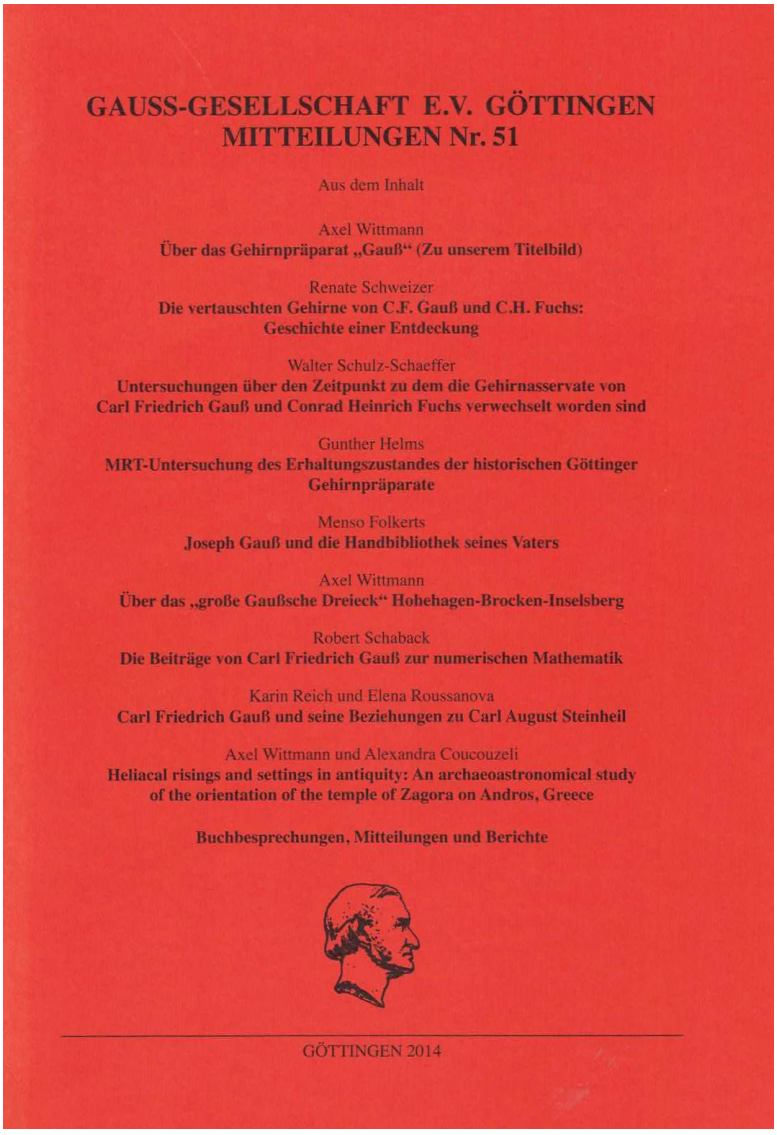
# MRI examination of the state of preservation of the historical Göttingen brain specimens

**Gunther Helms**

**Translated from the German original in the Publications of the Gauss Society Göttingen, 2014**

**Cite as: Helms G. MRT-Untersuchung des Erhaltungszustandes der historischen Göttinger Gehirnpräparate. Mitt. Gauß-Ges. 2014 51:33-38.**

**Abstract.** The status of preservation of the historic brain specimen of C.H. Fuchs, C.F. Hermann and P.G. Lejeune Dirichlet from R. Wagner's collection of the 19th century has been investigated using modern magnetic resonance imaging techniques (MRI). A brief report about their properties and current state of preservation is given.



GAUSS-GESELLSCHAFT E.V. GÖTTINGEN
MITTEILUNGEN Nr. 51

Aus dem Inhalt

Axel Wittmann
**Über das Gehirnpräparat „Gauß" (Zu unserem Titelbild)**

Renate Schweizer
**Die vertauschten Gehirne von C.F. Gauß und C.H. Fuchs: Geschichte einer Entdeckung**

Walter Schulz-Schaeffer
**Untersuchungen über den Zeitpunkt zu dem die Gehirnasservate von Carl Friedrich Gauß und Conrad Heinrich Fuchs verwechselt worden sind**

Gunther Helms
**MRT-Untersuchung des Erhaltungszustandes der historischen Göttinger Gehirnpräparate**

Menso Folkerts
**Joseph Gauß und die Handbibliothek seines Vaters**

Axel Wittmann
**Über das „große Gaußsche Dreieck" Hohehagen-Brocken-Inselsberg**

Robert Schaback
**Die Beiträge von Carl Friedrich Gauß zur numerischen Mathematik**

Karin Reich und Elena Roussanova
**Carl Friedrich Gauß und seine Beziehungen zu Carl August Steinheil**

Axel Wittmann und Alexandra Coucouzeli
**Heliacal risings and settings in antiquity: An archaeoastronomical study of the orientation of the temple of Zagora on Andros, Greece**

**Buchbesprechungen, Mitteilungen und Berichte**

GÖTTINGEN 2014

"*Gehirnsammlungen dürfen neben den Schädelsammlungen nicht fehlen ... wenn die Phrenologie eine festere reale Grundlage erhalten soll…*" (Wagner 1859).

Phrenology, devised by Franz Joseph Gall (1758-1828) but now considered a pseudoscience, was the first attempt to localize intellectual, emotional, and personality traits in specific brain regions and correlate their expression with the size of anatomical features. In 1855, the Göttingen physiologist and anatomist Rudolph Wagner (1805-1864) began to collect the brains of 'intelligent men'—that is, deceased professor colleagues—fixed in 'spirit of wine' to retain their shape. The hemispheres of the cerebrum were separated, and the brainstem and cerebellum were severed at the level of the midbrain. Not least for reasons of reverence, four of Wagner's brain specimens have been preserved in their original containers: They belong to Carl Friedrich Gauss (CFG, died 78 years of age on February 23, 1855), Conrad Heinrich Fuchs (CHF, 51, December 2, 1855), Carl Friedrich Hermann (CFH, 51, December 31, 1855), and Peter Gustav Lejeune Dirichlet (PGLD, 54, May 5, 1859). The brains of the mineralogist Friedrich Hausmann (1782-1859) (Mania 2009), a 29-year-old woman, and the 'manual worker' Krebs (Wagner 1864) have not been preserved. Following the discovery of Gauss's brain in the container marked "C. H. F__s" (Schweizer et al. 2013), the other specimens were taken from their containers, photographed, weighed (Table 1) and scanned on April 5, 2013. The corrected assignment of specimens (Table 1) is used in the following.

After removal from the ethanol storage liquid, which was yellowed by cholesterol and lipids, the specimens revealed a light, almost white color, as described by Hermann Wagner in his doctoral thesis (Wagner 1864). As the liquid evaporated, the surface acquired a brittle, pasty consistency susceptible to abrasion. The specimen CHF, which has been preserved in 3.7% w/v formalin solution since November 1998 (renewed in March 2011), displayed a firmer consistency but also showed the most severe surface damage. This is certainly attributable to the fact that this specimen, mistakenly attributed to Gauss, was certainly taken out more frequently. Figure 1 shows, in comparison to the historical lithograph, the superficial damage to this brain, which derives its 'richly convoluted' appearance from the division of the central and postcentral sulcus (Schweizer et al. 2014). The storage liquid of the CFH specimen smelled distinctly of long-chain alcohols. Contrary to original assumptions, these may be the 'impure alcohol' mentioned by R. Wagner's assistant, W. Kühne (quoted in H. Wagner, p. 16) rather than have been added later. From the density of 0.917 kg/l of the 'pure alcohol' stated there, an ethanol content of 49% v/v of the 'spirit of wine' used can be deduced. Since Hermann's and Dirichlet's brains are not mentioned in H. Wagner's work, it is quite possible that these vessels have never been opened after R. Wagner's death in 1864.

The condition and morphology of the brains were digitally documented using magnetic resonance imaging (MRI). A whole-body MRI scanner with a static field of 3T (Magnetom Tim Trio, Siemens Healthcare, Erlangen) and an eight-channel head coil were used. The specimen CHF (which had undergone additional formalin-fixation) was assembled in an open bowl and covered with distilled water; the specimen CFH was assembled and covered with the fluid of its container to reduce buoyancy. The presumably untouched specimen GLJD was examined in its historical glass container. Since it did not fit into the 8-channel coil, a circularly polarized head coil was used. The specimen CFG had previously been examined at the Biomedical NMR Research GmbH at the Max Planck Institute for Biophysical Chemistry using an identical MRI scanner. Details are listed in Table 2. A three-dimensional (3D) encoding method with 1 mm

resolution and T1 weighting (3D Turbo-FLASH with 900 ms inversion time and 9° readout angle) was used. This creates high contrast at the specimens' surface by suppressing the strong signal from the fixation fluid. Quantitative mapping of the contrast-determining longitudinal relaxation rate R1 and the signal amplitude was performed using a 3D FLASH ('Fast Low Angle Shot'; Frahm et al. 1986) (Helms et al. 2008). To achieve a high resolution of 0.5 mm and 0.6 mm, respectively, eight gradient echoes were acquired, which exhibit an in-phase summation of water and fat signals at echo times TE = $n$* 2.46 ms ($n$ = 1,… 8). Averaging these signals time-efficiently increases the signal-to-noise ratio, while local image distortions are reduced by the high bandwidth of the signal acquisition (Helms and Dechent 2009).

As previously reported (Wittmann et al. 1999), the T1-weighted images showed a characteristic contrast reversal between the cortex and the white matter (Fig. 2). In contrast to in vivo, the gray matter showed a higher intensity than the white matter, which can be explained as an effect of the washout of cholesterol and lipids from the white matter. However, since the gray matter clearly contrasts with the white matter, the MRI images can be used for studies of cortical morphology (Schweizer et al. 2014). To compensate for the anisotropic shrinkage and the displacement of the parts during the measurement reported in H. Wagner's dissertation, a digital mask was manually created for each image, and the image points were mapped onto a so-called brain template using an affine spatial transformation. This template of the Montreal Neurological Institute (MNI) is the average of the non-linearly superimposed T1-weighted brain MRIs of 152 healthy subjects. This digital montage yields a more suggestive image of the surface, while preserving the relative arrangement of the image points (Fig. 2). However, stronger shrinkage effects were observed at the inner edges of the corpus callosum and the midbrain. This preliminary work also serves to apply modern computerized methods for determining and visualizing cortical folding. Masking also allows the median surface to be visualized (Fig. 3).

Only at the higher resolution of the quantitative measurement did it become clear that in all specimens the white matter is densely permeated by fluid-filled, elongated cavities that follow the course of the nerve fibres. Although these are recognizable, the partial volumes of fluid and tissue average with varying proporton in each voxel. The typical lateral extent of the cavities is therefore approximately 0.5 mm or less. On the maps of the longitudinal relaxation rate R1 = 1/T1 (Fig. 4), these cavities are most clearly visible in the CHF specimen, even in comparison to the CFH, whose three-dimensional image grid is based on the same voxel size of 0.125 µl.

This feature appears much less pronounced in the specimen of PGLD, probably due to the larger voxel size of 0.216 µl. The degeneration is most advanced in the CHF specimen, although it remains unclear whether this is due to the more frequent removal or to the subsequent fixation with formaldehyde. The latter caused an increase in the relaxation rate through the formation of permanent chemical bonds, so that the histogram—particularly pronounced in the gray matter—shows conspicuously higher R1 values than in the specimens stored in alcohol. Significant differences in the R1 histograms were also observed between these brains, with the CFH specimen exhibiting the slowest relaxation values, corresponding to T1 times between 150 ms and 300 ms. Thus, during the 900 ms preparation phase of the 3D Turbo-FLASH sequence, complete relaxation of magnetization to its equilibrium state occurs in the tissue, so that the slice partitions here are encoded similar to a FLASH experiment.

Due to the fine and uniform structure of the white matter degeneration, age-typical perivascular changes can still be visualized on the R1 maps in Gauss's brain. The more pronounced atrophy is clearly visible compared to his colleagues who died in their prime. The lacunar changes in the basal ganglia may indicate chronic hypertension and could explain the weakness of movement in Gauss's last months of life (Mania 2008). The irregular signal alterations in the white matter of PGLD do not follow a known pathological pattern. One may speculate that these could have been caused by incipient autolysis, since Dirichlet died in May, while the others died in the winter months. The basal ganglia of CHF show bi-hemispheric incisions from below made during the dissection.

Since the fixation of brain tissue with alcohol is no longer common practice, there is no practical knowledge or studies on this subject matter. Even Wagner himself reported only cursorily, emphasizing the preservation of shape (Wagner 1859). The fixation process was therefore replicated using a bovine brain. This is relatively large compared to other livestock, weighing approximately 500 g, and has a compact white substance. The meninges were removed, but the brain was not dissected and stored in a cool, buffered physiological saline solution for 27 hours until the first MRI measurement. After rinsing with distilled water, the brain was immersed in commercially available ethyl alcohol, which was changed weekly, increasing the concentration from 50% to 70% to 90%, and stored at 94%. After just three days, the typical yellowing of the alcohol, bleaching of the surface, and a weight loss that totaled 35% after four weeks were apparent. This corresponds approximately to the weight loss noted on the labels of the glass containers: 32% from 1492 g to 1016 g for CFG, and 27% from 1499 g to 1089 g for CHF. Note that the weight of the specimens in Table 1 (CFG 975 g, CHF 978 g) includes the liquid in the cavities, thus incompletely reflecting the loss of substance.

The 3D Turbo-FLASH image series in Fig. 5 shows the fresh bovine brain and the progress of fixation, which stabilized after two months. The high intensity indicates the initial penetration of the amphiphilic alcohol through denaturation of proteins, membranes, and DNA. The subsequent leaching of cholesterol and lipids destroys the contrast between the cortex and the white matter. Parallel to the shrinkage of the specimen, a greatly reduced contrast reappears, starting from the outside. Even after one year of storage, no change in contrast was observed, although the surface was already sensitive to mechanical abrasion. The T1 times of 1000 ms are significantly longer than in the historical specimens. The change in T1-contrast and the white matter degeneration of the historic brains are therefore attributable to the long storage period.

In contrast to formalin fixation, which stiffens the tissue through cross-links but preserves its microstructure, ethanol fixation causes significant shrinkage and microstructural changes, resulting in unusual image contrast. However, even after 150 years, tissue lesions can still be detected by MRI in the presence of free fluid.

**Acknowledgements:**
Personal thanks to Prof. Jens Frahm and Dr. Renate Schweizer, Biomedical NMR Research Inc. at the Max-Planck-Institute for Biophysical Chemistry, Göttingen, for the invitation to participate in this study, and to Dr. Axel Wittmann, Gauss-Society Göttingen and PD Dr. Walter Schulz-Schaeffer, Institute for Neuropathology, Göttingen University Medical Center for valuable information and support.

**Literature:**


Frahm, J., Haase, A., Matthaei, D. (1986). *Rapid three-dimensional MR imaging using the FLASH technique.* J Comput Assist Tomogr. 10(2):363-368.

Helms, G., Dathe, H., Dechent, P. (2008). *Quantitative FLASH MRI at 3T using a rational approximation of the Ernst equation.* Magn Reson Med 59:667-672.

Helms, G., Dechent, P. (2009). *Increased SNR and reduced distortions by averaging multiple gradient echo signals in 3D FLASH imaging of the human brain at 3 Tesla.* J Magn Reson Imaging 29(1):198-204.

Mania, H. (2009). *Gauß. Eine Biographie,* Rowohlt Taschenbuch Verlag, Reinbek bei Hamburg.

Schweizer, R., Wittmann, A., and Frahm, J.: 2013, *A rare anatomical variation newly identifies the brains of C.F. Gauss and C.H. Fuchs in a collection at the University of Göttingen,* Brain 10.1093/brain/awt296. doi: 10.1093/brain/awt296. printed version: Brain 137, e269 (April 2014).

Schweizer, R., Helms, G., Frahm, J. (2014). *Revisiting a historical brain with magnetic resonance imaging – clarifying the first description of a divided central sulcus.* Front. Neuroanat. 19 May doi: 10.3389/fnana.2014.00035

Wagner, H. (1864). *Maassbestimmungen der Oberfläche des grossen Gehirns.* Inauguraldissertation, Universität Göttingen.

Wagner, R. (1859). *Kritische und experimentelle Untersuchungen über die Funktionen des Gehirns.* in: Zeitschrift für rationelle Medicin, 3. Band, 5. Reihe (Hrsg. J. Henle, C. v. Pfeufer), Heidelberg und Leipzig.

Wagner, R. (1860). *Über die typischen Verschiedenheiten der Windungen der Hemisphären und über die Lehre vom Hirngewicht, mit besondrer Rücksicht auf die Hirnbildung intelligenter Männer.*, in: *Vorstudien zu einer wissenschaftlichen Morphologie und Physiologie des menschlichen Gehirns als Seelenorgan.* (Göttingen: Verlag der Dieterichschen Buchhandlung).

Wagner, R. (1862). *Über den Hirnbau der Mikrocephalen mit vergleichender Rücksicht auf den Bau des Gehirns der normalen*
*Menschen und der Quadrumanen.,* in: *Vorstudien zu einer wissenschaftlichen Morphologie und Physiologie des menschlichen Gehirns als Seelenorgan.* (Göttingen: Verlag der Dietrichschen Buchhandlung).

Wittmann, A.D., Frahm, J., Haenicke, W. (1999). *Magnetresonanz-Tomographie des Gehirns von Carl Friedrich Gauß.* Mitt. Gauß-Ges. 36**,** 9-19.



Author affiliation:
Dr. Gunther Helms
MR-Forschung in der Neurologie und Psychiatrie
Abteilung Kognitive Neurologie
Universitätsmedizin Göttingen
Robert-Koch-Str. 40
37075 Göttingen
e-mail: ghelms@gwdg.de

New address as of 1.9.2014:

Medical Radiation Physics
Dept. of Clinical Sciences
Lund University
Box 117
SE-22310 Lund, Sweden
gunther.helms@med.lu.se

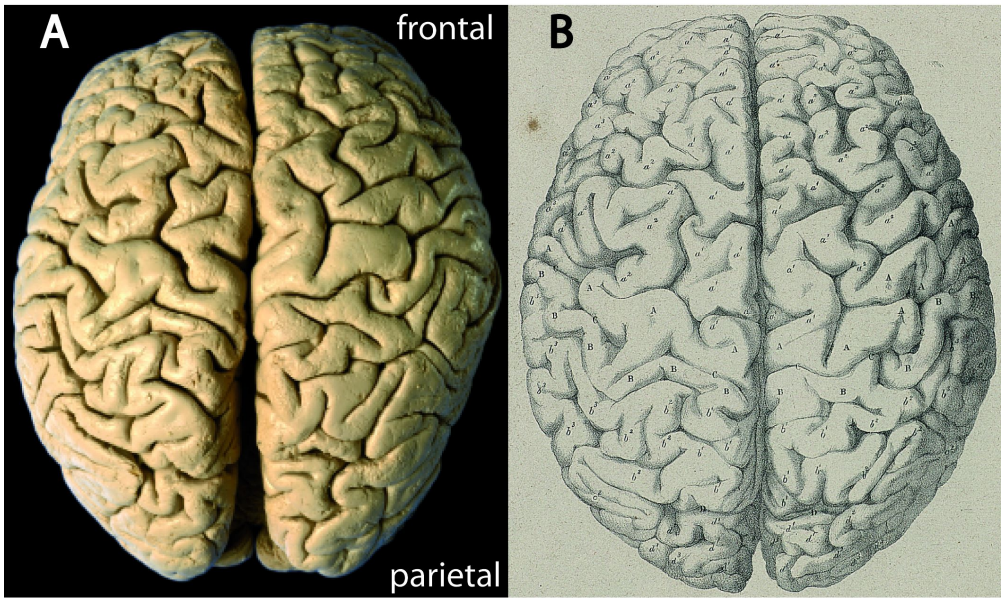
Table 1: Net drained weights of the specimens on April 5th, 2013

| | Left Hemisphere | Right Hemisphere | Cerebellum and Brainstem |
|---|---|---|---|
| Jar Hermann, CFH | 425.1 g | 418.5 g | 132.0 g |
| Jar Gauß, CHF | 436.0 g | 432.4 g | 109.6 g |
| Jar Dirichlet, PGLD | 474.6 g | 473.9 g | 130.0 g |
| Jar Fuchs, CFG | 424.6 g | 420.6 g | 129.5 g |

Table 2: Set-up details of the MRI examinations

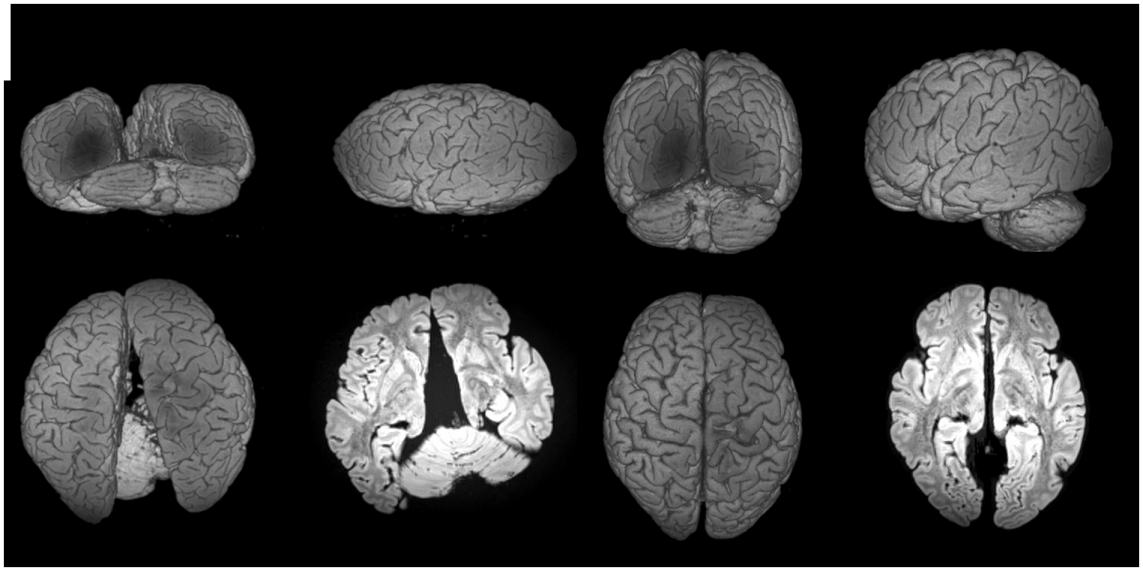
| | liquid | RF coil | vessel | resolution |
|---|---|---|---|---|
| CFG | Aqua bisdest. | 32-channel coil | Plastic bag | 0.6 mm |
| CHF | Acqu bidest. | 8-channel coil | Plastic bowl | 0.5 mm |
| CFH | 'impure alcohol' | 8-channel coil | Plastic bowl | 0.5 mm |
| PGLD | 'pure alcohol' | Birdcage head coil | Orig glass jar | 0.6 mm |

Figure 1: Top view of the 'richly convoluted' specimen CHF



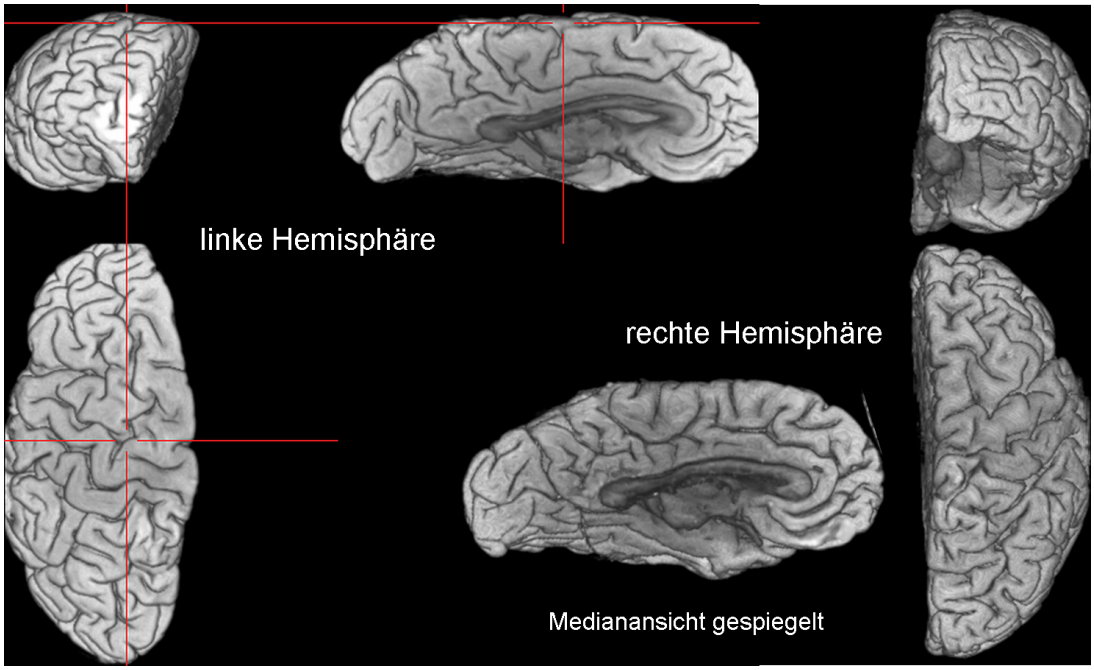

The recent photograph (A) shows significant damage to the surface; in particular in frontal, but also parietal-paramedian locations, when compared to the historical lithography (B) in (Wagner 1860).

Figure. 2: Digital montage of the brain of PGLD scanned in situ.



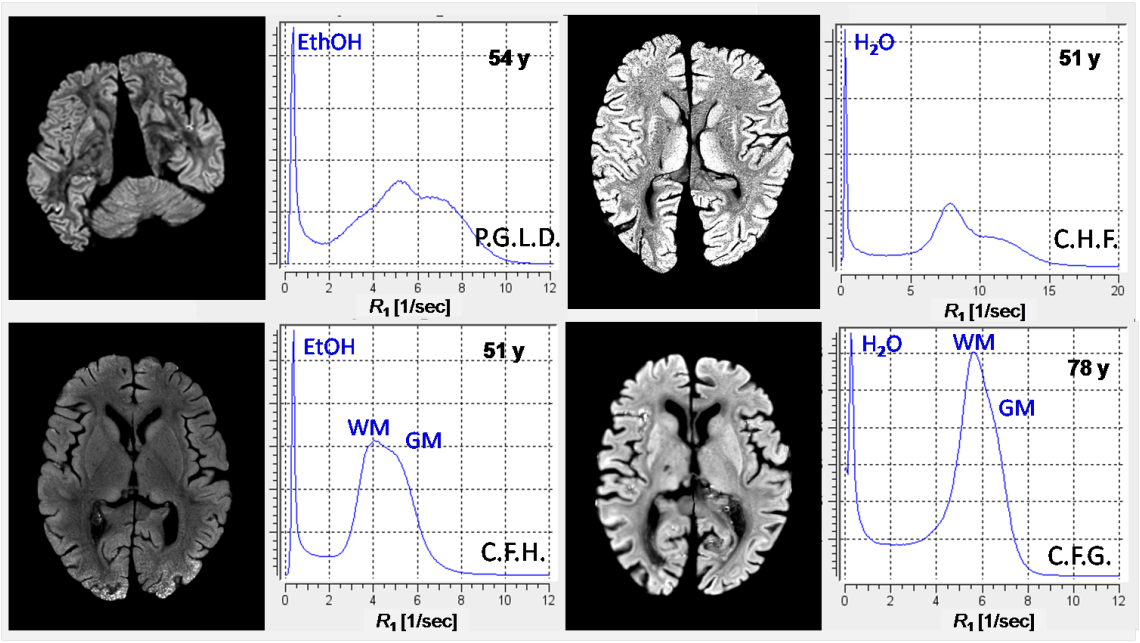
Shown are the surface reconstruction and a transverse cross-section the T1-weighted Turbo-FLASH image of PGLD. Left: The original dataset shows the position of the individual parts in situ and varying distortions. Right: These are largely corrected after affine registration of the individual parts to a brain template, resulting in a more natural representation but changed volume. In this non-quantitative MRI technique, the low intensity at the pole of the occipital lobe and the high intensity in the interior are due to the excitation and reception characteristics of the birdcage RF coil.

Figure 3: Surface views of the cerebral-hemispheres of Gauß' brain



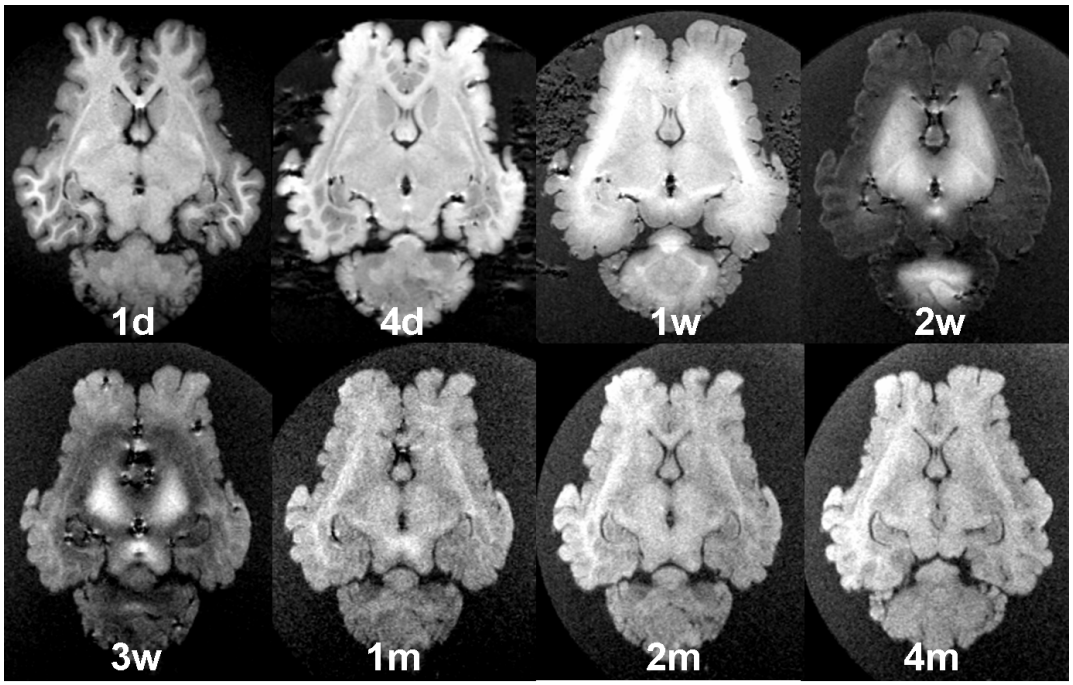

Digital masking of the 3D dataset allows for separate visualization of the hemispheres, e.g. to reveal the median surfaces. To facilitate visual comparison, the right view has been mirrored and slightly tilted. The severed corpus callosum and the optic nerve endings are clearly visible. The crosshairs reference the position of an image point in all three views.

Figure 4: Relaxation maps und histograms




Variation of R1 values reflect the preparation of specimens, preservation state,.and surrounding liquid. Note the different scale used for CHF.

Figure 5: Serial 3D Turbo-FLASH monitoring of ethanol fixation.




Transverse view of a bovine brain. The high intensity indicates the initial penetration of the alcohol through denaturation of proteins, membranes, and DNA. The subsequent leaching of cholesterol and lipids destroys the contrast between the cortex and the medulla. Parallel to the shrinkage of the specimen, a greatly reduced contrast reappears, starting from the outside.