Susceptibility Weighted Imaging

Opening new doors to clinical applications of magnetic resonance imaging

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Susceptibility Weighted Imaging (SWI)  
Creating New Insights in Neuro-Imaging  

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Images courtesy of Juergen Reichenbach, PhD, Klinikum der Freidrich-Schiller-Univ, Jena, Germany

Susceptibility Weighted Imaging (SWI)  

Occult Vascular Disease such as Cavernomas, Angiomas, Telangiectasias

Occult venous disease implies a change in vascularity that is hard to find, sometimes even with the aid of a contrast agent. Here we observe that the spider-like effect of this angioma is easily seen with the SWI technique even without a T1 reducing contrast agent.
Trauma for Both Adults and Children

The detection of microhemorrhages, shearing and diffuse axonal injury (DAI) in trauma patients is difficult. Using SWI, we can see very small lesions. SWI is extremely sensitive to bleeding in the gray matter/white matter boundaries. Here, an example of purported DAI is shown compared to a conventional gradient echo image of the same area. Perhaps by following the resolution of hemorrhage in the brain, along with spectroscopic imaging, it may be possible to better monitor the internal improvement of coma patients.

Diffuse axonal injury (top two images) and hemorrhage in a trauma case (bottom two images). Conventional gradient echo images with TE=20ms (2 left images) show a hint of hemorrhage inside the ventricles and slight white matter abnormalities. The SWI TE=40 ms images show clearly hemorrhage at the junction of white and gray matter (top right, arrows) and inside the ventricles and other areas (bottom right).

Images courtesy of Karen Tong, MD, Loma Linda University, Loma Linda, CA
Susceptibility Weighted Imaging
(also referred to as SWI)

We have developed a new type of contrast in MRI different from spin density, T1, or T2 imaging. This new method exploits the susceptibility differences between tissues. We refer to this method as Susceptibility Weighted Imaging*. SWI uses a fully velocity compensated, three dimensional, rf spoiled, high-resolution, 3D gradient echo scan. Signal from substances with different susceptibilities than their neighboring tissues (such as venous blood, or hemorrhage, for example) will become out of phase with adjacent tissues at sufficiently long echo times. If the size of the source is smaller than a voxel then the signal from this substance will beat against that of its neighbor creating a powerful partial volume effect. SWI can be run on any manufacturer’s machine at field strengths of 1.0T, 1.5T, 3.0T and higher.

**What is Susceptibility Weighted Imaging and How Can it Help?**

SWI is a unique combination of the following features:

- High resolution 3D gradient echo imaging
- Full flow compensation in all three directions
- Thin slices to avoid signal losses
- Filtering of phase images to reduce unwanted field effects
- Creating a phase mask image
- Operating on the magnitude image with the phase mask

This special data acquisition and image processing produces: an enhanced contrast magnitude image which is exquisitely sensitive to venous blood, hemorrhage and iron storage. SWI offers you the potential for:

- Better diagnosis of disease
- Better follow up for longitudinal studies
- An opportunity to be involved in the clinical evaluation of a new concept
- An opportunity to open new doors in clinical MRI

*The mechanisms behind susceptibility weighted imaging are protected via US Patent No. 6501272 B1 issued 31 December, 2002. Dr. E. Mark Haacke is the primary inventor of SWI along with his fellow co-inventors both Dr. Juergen Reichenbach and Dr. Yi Wang. Dr. Haacke also has another patent pending on both data collection and processing aspects of SWI (US 2002 P 06624 and PCT/US03/13918).
Stroke and Hemorrhage

Diffusion weighted imaging offers a powerful means to detect acute stroke. Although it is well known that gradient echo imaging can detect hemorrhage, it is best detected with SWI. In the example shown here, the diffusion image shows the region of likely cytotoxic edema whereas the SW image shows the likely localization of the stroke and the vascular territory affected.

Figure Caption:

The bright region in the diffusion weighted image shows the area affected in this acute stroke example. The arrows in the SWI image may show the tissue at risk that has been affected by the stroke (A, B, C) and the location of the stroke itself (D). The reason that we are able to see the affected vascular territory could be because there is a reduced level of oxygen saturation in this tissue, suggesting that the flow to this region of the brain could be reduced post stroke. Another possible explanation is that there is an increase in local venous blood volume. In either case, this image suggests that the tissue associated with this vascular territory could be tissue at risk.

Images courtesy of Daniel Wycliffe, MD, Loma Linda University, Loma Linda, CA
Published Research and Clinical Papers

1. **Small Vessels in the Human Brain: MR Venography with Deoxyhemoglobin as an Intrinsic Contrast Agent**
   Radiology 204; 272-277; 1997.

2. **High-Resolution Venography of the Brain Using Magnetic Resonance Imaging**
   MAGMA 6; 62-69; 1998.

3. **Comparison of Functional Venography and EPI-BOLD-fMRI at 1.5T**

4. **MR High-Resolution Blood Oxygenation Level - Dependent Venography of Occult (Low-Flow) Vascular Lesions**
   AJNR 20; 1239-1242; 1999.

5. **High-Resolution MR Venography of Cerebral Arteriovenous Malformations**

6. **Spatial Selectivity of BOLD Contrast: Effects In and Around Draining Veins**

7. **Improving High-Resolution MR Bold Venographic Imaging Using a T1 Reducing Contrast Agent**
   JMRI 10; 118-123; 1999.

8. **High-Resolution MR Venography at 3 Tesla**
   JCAT 24; 949-957; 2000.
Hemorrhage and Venous Vasculature in Tumors

This is a post-contrast T1 weighted scan showing 2 brain metastases.

Using the SWI method, new details show up related to hemorrhage and venous vasculature.

Images courtesy of Vivek Sehgal, MD, Wayne State University, Detroit, MI

Detection of Hemorrhage in Tumors with SWI

A pre-contrast T1 weighted scan of a brain metastasis which doesn’t show any hint of hemorrhage.

Using the SWI method, there is evidence of blood products which have been confirmed by pathology.

Images courtesy of Vivek Sehgal, MD, Wayne State University, Detroit, MI
9. **MR Venography of Multiple Sclerosis**

10. **High-resolution Blood Oxygen-Level Dependent MR Venography (HRBV): A New Technique**

11. **High-Resolution BOLD Venographic Imaging: A Window into Brain Function**
Jürgen R. Reichenbach, E. M. Haacke.

12. **Improved Target Volume Characterization in Stereotactic Treatment Planning of Brain Lesions by Using High-Resolution BOLD MR-Venography**.
L. Schad.

13. **High Resolution MR-Venography of Cerebral Arteriovenous Malformations**

14. **Improved Detection of Hemorrhagic Shearing Lesions in Children with Post-traumatic Diffuse Axonal Injury-Initial Results**

15. **Enhanced BOLD MR-Venography (CE-MRV) of Brain Tumors at 3 Tesla: First Clinical Experience**
(Investigative Radiology 2003—in Press)

16. **Susceptibility Weighted Imaging of Brain Masses**
Enhanced Detection of Tumors

The development of susceptibility weighted imaging (SWI) has opened the door for improved contrast and improved detection of hemorrhage in tumors. Part of the characterization of tumors lies in understanding the angiographic behavior of lesions both from the perspective of angiogenesis and micro-hemorrhages. Aggressive tumors tend to have rapidly growing vasculature and many microhemorrhages. Hence, our ability to detect these changes in the tumor could lead to a better determination of the tumor status. The enhanced sensitivity of SWI to venous blood and blood products due to their differences in susceptibility compared to normal tissue leads to better contrast in detecting tumor boundaries and tumor hemorrhage.

An Occult Tumor Example

SWI shows nicely regions of venous vascular content and hemorrhage in the tumor not seen with the conventional T1 weighted post-contrast scan.

Images courtesy of Daniel Kido, MD, Loma Linda University, Loma Linda, CA

Images courtesy of Vivek Sehgal, MD, Wayne State University, Detroit, MI
International Recognition of Susceptibility Weighted Imaging

The following awards have been made for research in SWI.

1998

- **Marie-Sklodowska-Curie Prize**
  “Visualization of Cerebral Venous Structures Using High Resolution MRI”
  J.R. Reichenbach, L.R. Schad, M. Essig, E.M. Haacke, W.A. Kaiser

2000

- **Poster Prize of the XXVI Congress of European Society of Neuroradiology 2000**
  "High-Resolution Blood Oxygen Level Dependent MR Venography"
  ESNR 2000 XXVI Congress and XI Advanced Course, September 10-13, 2000, Oslo, Norway

2002

- **The ECR 2002 European Congress of Radiology: Scientific Exhibition Award**
  ECR 2002 Cum Laude
  "Clinical Applications of High-Resolution BOLD Venography"
  J.R. Reichenbach, C. Fitzek, L. Jonetz-Mentzel, D. Sauner, H.J. Mentzel,
  E.M. Haacke, W.A. Kaiser
  ECR 2002 European Congress of Radiology, March 1-5, 2002, Vienna, Austria.
  Eur Radiol 2002; 12(2), Suppl. 1:459

- **The ECR 2002 Research & Education Fund: Nycomed Amersham Research Fellowship Grant**
  "High-Resolution Venographic BOLD Imaging of the Human Brain and Its Application to Brain Lesions"
  J.R. Reichenbach. ECR 2002 European Congress of Radiology, March 1-5, 2002, Vienna, Austria

- **The German Röntgen Society awarded the Walter-Friedrich-Award**
  “High Resolution Angiography of the Human Brain-Development and Trial of a New Method of Magnetic Resonance Tomography (BOLD-Angiography)”
  Juergen Reichenbach's Habilitation

- **The Derek Harwood-Nash Award for the Best Paper in Pediatric Neuroradiology was presented by the American Society of Pediatric Neuroradiology at their Annual Meeting**
  "Improved Detection of Hemorrhagic Shearing Injuries in Children with Post-Traumatic Diffuse Axonal Injury Using Susceptibility Weighted Imaging: Correlation with Severity and Outcome."
  Karen A. Tong, MD
Small Vessel Imaging

Imagine the ability to image vessels smaller than a voxel, as small as deep white matter vessels. With SWI, this is now possible for venous blood. Using 1.5T systems you can visualize veins on the order of a few hundred microns with 1 mm³ resolution in imaging times of roughly 5 to 10 minutes. Using 3.0T systems, imaging time can be reduced or resolution increased.

Exquisite representation of small veins in the brain for both the medial and peripheral drainage systems in the brain.

Data courtesy of Weili Lin, PhD, University of North Carolina, Chapel Hill, NC.

Processing performed using SPIN software from the MRI Institute for Biomedical Research.

Compare the in-vivo SWI results above to the radiologic images from a cadaver brain shown on the right.

Image courtesy of Georges Salamon, MD, University of California Los Angeles (UCLA), Los Angeles, CA
The Advantages of High Field

The images from higher field strengths are generally of higher quality than the lower field strengths because of the increased SNR. The higher the field strength, the better the results, the better the signal-to-noise, and the better the coverage in a fixed period of time. On the other hand, we can trade-off signal-to-noise to obtain even higher resolution. Here we show an example from a 3T system where the vessels are now labeled; these images serve as an important educational tool.

Vascularization at the level of:

Caudate, Striatum, Orbito-frontal, and Temporo-parietal areas.

Images courtesy of Jay Gorell, MD, Henry Ford Hospital, Detroit, MI
Labeled figures courtesy of Georges Salamon, MD, UCLA, Los Angeles, CA
Mineralization, Iron and Hemorrhage in the Basal Ganglia

The standard method to evaluate mineralization in the basal ganglia has been using Computed Tomography (CT). Now SWI offers a more sensitive means to pick up abnormalities in iron and calcium in these regions.

Conventional CT Scan

Mineralization in the globus pallidus (barely seen in the accompanying CT image).

Images courtesy of Daniel Kido, MD, Loma Linda University, Loma Linda, CA

SWI at 1.5T

Mineralization in the globus pallidus (barely seen in the accompanying CT image).

Images courtesy of Daniel Kido, MD, Loma Linda University, Loma Linda, CA

Hypertension

An example of hemorrhages in the basal ganglia and other parts of the brain. SWI can show effects on the order of a few cubic millimeters.

Images courtesy of Djamel Haddar, MD, Wayne State University, Detroit, MI
Current Ongoing Research Studies

- **The Role of SWI in High Resolution fMRI Studies**
  Supported in part by the National Institutes of Health HL62983 Grant

- **Evaluation of the Brain’s Vascular Response to Caffeine**
  Supported in part by the National Institutes of Health HL62983 Grant

- **Imaging Brain Iron in Alzheimer’s Disease**
  Supported in part by the National Institutes of Health AG20948 Grant

- **Improved Characterization of Tumors in MRI Using SWI**
  National Institutes of Health Grant, *In Review*

- **Detecting Hemorrhage and Diffuse Axonal Injury in Trauma**
  National Institutes of Health Program Project Grant, *In Preparation*

- **Clinical Implementation of SWI**
  Supported in part by Siemens Medical Solutions, Inc.

References to Research Papers Using SWI

We wish to thank all those involved in what can only be called a major international collaboration by the following people, to whom goes my utmost thanks and appreciation for their participation in and promotion of this research and its clinical applications.

*Research collaborators:* Professors Weili Lin, Song Lai, Juergen Reichenbach, Ewald Moser, Lothar Schad, Doctors Markus Barth, Frank Hoogenraad, and Mr. Yingbiao Xu.

*Clinical collaborators:* Professors Daniel Kido, Karen Tong, Daniel Wycliffe, Vivek Sehgal, Djamel Haddar, Zach Del Proposto and Benjamin Lee.

Finally, we point out that the name for this method has evolved from HRBV (high resolution BOLD venographic imaging) to AVID BOLD (applications of venous imaging in detecting disease) to the simpler and more generic acronym SWI (susceptibility weighted imaging). The method is also sometimes referred to as BOLD MR Venography and when a contrast agent is used contrast enhanced MRV. However, one might consider HRBV, MRV or AVID BOLD (which all refer to the same method) as a subset of SWI focusing on veins only, whereas SWI can visualize other effects such as the presence of hemosiderin or iron in the form of ferritin.
Phase and Alzheimer’s Disease

The use of filtered phase images themselves is often useful in that they show not only the presence of veins and hemorrhage but also they are perhaps an indicator of iron content. The contrast between the gray matter and the CSF or white matter is presumably due to the increased iron content in the gray matter. It is thought that iron around beta amyloid plaque or other sources of iron may be an indication of the early development of Alzheimer’s disease.

Dentate Nucleus

After filtering the phase, it becomes possible to see contrast between iron laden tissues and surrounding tissues. Here we see the contrast not otherwise visible on the T1 weighted images. The arrows show (A) the dentate nucleus and (B) the right cerebellar hemisphere.

Susceptibility Weighted Imaging (SWI)
FOR MORE INFORMATION ABOUT

*Susceptibility Weighted Imaging*

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**APPOINTMENTS:**

- Professor of Radiology and Biomedical Engineering
  Wayne State University, Detroit, Michigan

- Professor of Radiology
  Loma Linda University, Loma Linda, California

- Professor of Physics
  Case Western Reserve University, Cleveland, Ohio

*Dr. Haacke is the director of The MR Research Facility at Wayne State University and he is also the director of The MRI Institute for Biomedical Research in Detroit, Michigan.*