

Session: “Everything you wanted to know about magnetic susceptibility and why it is important”

Speaker: Karen A. Tong ktong@llu.edu

Highlights: SWI is changing clinical medicine, and is no longer considered a “research tool”!

Talk title: *Yes, It is Exciting but Where are the “Killer Apps”?*

Target audience – those interested in using susceptibility-weighted imaging in clinical practice

Outcome/objectives – to identify clinical areas that benefit from the SWI technique, in order to have the most significant impact.

Discussion:

Susceptibility weighted imaging (SWI) has proven to be superior to conventional MRI in the evaluation of many neurological conditions:

- This is especially true for detection of hemorrhages in many disorders. Often the hemorrhages may only be visible on SWI, and diagnoses would not have been made correctly without this technique:
 - SWI better demonstrates the extent of traumatic brain parenchymal injury in the acute clinical setting.
 - SWI better demonstrates acute parenchymal hemorrhage in many conditions including coagulopathy, leukemia, hemorrhagic encephalitis, vasculitis.
 - SWI better demonstrates chronic microhemorrhages, which may be the only supporting evidence of some diseases (short of autopsy), such as amyloid angiopathy, but also in chronic hypertension, Alzheimer disease, post-radiation therapy, post-cardiac bypass.
 - SWI can even be used to detect hemorrhage in acute cervical spinal cord injury.
- SWI has also provides greater clinical information regarding stroke, even without the presence of hemorrhage.
 - SWI can show the location and extent of arterial thrombus in the setting of acute infarct, even without or possibly better than MRA.
 - SWI can show increased oxygen extraction in the setting of acute or chronic ischemia, or hypoxia; and can imply penumbra even without PWI.
 - SWI can show the location and extent of cortical venous thrombus, even possibly better than MRV.
 - SWI can help guide the management of stroke patients, whether for excluding patients from thrombolytic therapy, or for determining whether antiplatelet therapy may be required after thrombolytic treatment.
- SWI has been established as a superior technique for detecting and monitoring venous anomalies and vascular malformations of all types, including telangiectasias, cavernomas, Sturge-Weber syndrome, AVM or AVF.
- SWI has also been shown to improve the grading of gliomas and potentially distinguish between different types of brain tumors such as glioblastoma versus primary CNS lymphoma.
- SWI has dramatically improved the ability to diagnose neurodegenerative disorders, often associated with iron deposition or mineralization of the brain.

- SWI phase images can be used to clarify the etiology of hypointense foci that can be due to calcifications, microhemorrhages, iron deposition, or air.
- SWI can potentially be used to diagnose brain death and help guide issues of end-of-life care.

SWI has also been shown to be useful in the evaluation of non-neurological disorders, elsewhere in the body.

- To evaluate malignancies in the body including prostate cancer, hepatocellular carcinoma, renal cell carcinoma.
- To evaluate gynecological pathology such as endometriosis.
- To evaluate other abdominal pathology, such as splenic lesions associated with cirrhosis, portal hypertension or esophageal varices.

The next stage of SWI is here, using Quantitative Susceptibility Mapping (QSM)

- QSM has improved the understanding of anatomy and physiology of the brain, as well as other parts of the body.
- More “killer apps” will keep coming!

References

Akiyama Y, Miyata K, Harada K, Minamida Y, Nonaka T, Koyanagi I, Asai Y, Houkin K. Susceptibility-weighted magnetic resonance imaging for the detection of **cerebral microhemorrhage** in patients with traumatic brain injury. *Neurol Med Chir (Tokyo)*. 2009 Mar;49(3):97-9

Ayaz M, Boikov AS, Haacke EM, Kido DK, Kirsch WM. Imaging **cerebral microbleeds** using susceptibility weighted imaging: one step toward detecting vascular dementia. *J Magn Reson Imaging*. 2010 Jan;31(1):142-8.

Bae JW, Cha SY, Kang TH, Lee JH, Kim HJ, Jung DS, Kim EJ. Susceptibility-weighted imaging findings of subacute delayed **carbon monoxide intoxication**: a report of five cases. *Neurol Sci*. 2012 Jan 15;312(1-2):13-7.

Bai Q, Zhao Z, Sui H, Xie X, Chen J, Yang J, Zhang L. Susceptibility-weighted imaging for cerebral microbleed detection in super-acute **ischemic stroke patients treated with intravenous thrombolysis**. *Neurol Res*. 2013 Jul;35(6):586-93.

Bai Y, Wang MY, Han YH, Dou SW, Lin Q, Guo Y, Li W, Ding DG, Dai JP, Qin W, Shi DP, Tian J, Dai YM. Susceptibility weighted imaging: a new tool in the diagnosis of **prostate cancer** and detection of prostatic calcification. *PLoS One*. 2013;8(1):e53237.

Beauchamp MH, Beare R, Ditchfield M, Coleman L, Babl FE, Kean M, Crossley L, Catroppa C, Yeates KO, Anderson V. Susceptibility weighted imaging and its relationship to outcome after pediatric **traumatic brain injury**. *Cortex*. 2013 Feb;49(2):591-8.

Beauchamp MH, Ditchfield M, Babl FE, Kean M, Catroppa C, Yeates KO, Anderson V. Detecting **traumatic brain lesions** in children: CT versus MRI versus susceptibility weighted imaging (SWI). *J Neurotrauma*. 2011 Jun;28(6):915-27.

Bilgic B, Pfefferbaum A, Rohlfing T, Sullivan EV, Adalsteinsson E. MRI estimates of **brain iron concentration in normal aging** using quantitative susceptibility mapping. *Neuroimage*. 2012 Feb 1;59(3):2625-35.

Chang SX, Li GW, Chen Y, Bao H, Zhou L, Yuan J, Wu DM, Dai YM. Characterizing venous vasculatures of **hepatocellular carcinoma** using a multi-breath-hold two-dimensional susceptibility weighted imaging. *PLoS One*. 2013 Jun 14;8(6):e65895.

Charidimou A, Jäger HR, Werring DJ. Cerebral microbleed detection and mapping: principles, methodological aspects and rationale in **vascular dementia**. *Exp Gerontol*. 2012 Nov;47(11):843-52.

Cheng AL, Batool S, McCreary CR, Lauzon ML, Frayne R, Goyal M, Smith EE. Susceptibility-weighted imaging is more reliable than T2*-weighted gradient-recalled echo MRI for detecting **microbleeds**. *Stroke*. 2013 Oct;44(10):2782-6.

Dai Y, Zeng M, Li R, Rao S, Chen C, DelProposto Z, Haacke EM, Hu J, Renate J. Improving detection of siderotic nodules in **cirrhotic liver** with a multi-breath-hold susceptibility-weighted imaging technique. *J Magn Reson Imaging*. 2011 Aug;34(2):318-25.

de Souza JM, Domingues RC, Cruz LC Jr, Domingues FS, Iasbeck T, Gasparetto EL. Susceptibility-weighted imaging for the evaluation of patients with **familial cerebral cavernous malformations**: a comparison with t2-weighted fast spin-echo and gradient-echo sequences. *AJNR Am J Neuroradiol*. 2008 Jan;29(1):154-8

Deistung A, Schweser F, Wiestler B, Abello M, Roethke M, Sahm F, Wick W, Nagel AM, Heiland S, Schlemmer HP, Bendszus M, Reichenbach JR, Radbruch A. Quantitative susceptibility mapping differentiates between blood depositions and calcifications in patients with **glioblastoma**. *PLoS One*. 2013;8(3):e57924.

Essig MM, Reichenbach JR, Schad LL, Debus JJ, Kaiser WA. High resolution MR-venography of **cerebral arteriovenous malformations**. *Radiologe* 2001;41:288–295.

Frischer JM, Göd S, Gruber A, Saringer W, Grabner G, Gatterbauer B, Kitz K, Holzer S, Kronnerwetter C, Hainfellner JA, Knosp E, Trattnig S. Susceptibility-weighted imaging at 7 T: Improved diagnosis of **cerebral cavernous malformations and associated developmental venous anomalies**. *Neuroimage Clin*. 2012 Sep 14;1(1):116-20.

Gho SM, Liu C, Li W, Jang U, Kim EY, Hwang D, Kim DH. Susceptibility map-weighted imaging (**SMWI**) for neuroimaging. *Magn Reson Med*. 2013 Sep 4.

Haacke EM, Cheng NY, House MJ, Liu Q, Neelavalli J, Ogg RJ, Khan A, Ayaz M, Kirsch W, Obenaus A. Imaging **iron stores in the brain** using magnetic resonance imaging. Magn Reson Imaging 2005 Jan;23(1):1-25.

Haacke EM, DelProposto ZS, Chaturvedi S, Sehgal V, Tenzer M, Neelavalli J, Kido D. Imaging **cerebral amyloid angiopathy** with susceptibility-weighted imaging. AJNR Am J Neuroradiol. 2007 Feb;28(2):316-7.

Haacke EM, Garbern J, Miao Y, Habib C, Liu M. **Iron stores and cerebral veins in MS** studied by susceptibility weighted imaging. Int Angiol. 2010 Apr;29(2):149-57.

Haacke EM, Makki M, Ge Y, Maheshwari M, Sehgal V, Hu J, Selvan M, Wu Z, Latif Z, Xuan Y, Khan O, Garbern J, Grossman RI. Characterizing **iron deposition in multiple sclerosis lesions** using susceptibility weighted imaging. J Magn Reson Imaging. 2009 Mar;29(3):537-44.

Haacke EM, Mittal S, Wu Z, Neelavalli J, Cheng YC. Susceptibility-weighted imaging: technical aspects and **clinical applications**, part 1. AJNR Am J Neuroradiol. 2009 Jan;30(1):19-30.

Haacke EM, Xu Y, Cheng YC, Reichenbach JR. Susceptibility weighted imaging (**SWI**). Magn Reson Med 2004;52:612-8.

Haacke EM, Tang J, Neelavalli J, Cheng YC. Susceptibility mapping as a means to **visualize veins and quantify oxygen saturation**. J Magn Reson Imaging. 2010 Sep;32(3):663-76.

Habib CA, Liu M, Bawany N, Garbern J, Krumbein I, Mentzel HJ, Reichenbach J, Magnano C, Zivadinov R, Haacke EM. Assessing **abnormal iron content in the deep gray matter of patients with multiple sclerosis** versus healthy controls. AJNR Am J Neuroradiol. 2012 Feb;33(2):252-8.

Harder SL, Hopp KM, Ward H, Neglio H, Gitlin J, Kido D. **Mineralization of the deep gray matter with age**: a retrospective review with susceptibility-weighted MR imaging. AJNR Am J Neuroradiol. 2008 Jan;29(1):176-83.

Hermier M, Nighoghossian N. Contribution of susceptibility-weighted imaging to **acute stroke assessment**. Stroke 2004;35:1989-94.

Hingwala D, Kesavadas C, Thomas B, Kapilamoorthy TR. Clinical utility of susceptibility-weighted imaging in **vascular diseases of the brain**. Neurol India. 2010 Jul-Aug;58(4):602-7.

Hingwala DR, Kesavadas C, Thomas B, Kapilamoorthy TR. Susceptibility weighted imaging in the evaluation of **movement disorders**. Clin Radiol. 2013 Jun;68(6):e338-48.

Hopp K, Popescu BF, McCrea RP, Harder SL, Robinson CA, Haacke ME, Rajput AH, Rajput A, Nichol H. **Brain iron detected by SWI** high pass filtered phase calibrated with synchrotron X-ray fluorescence. J Magn Reson Imaging. 2010 Jun;31(6):1346-54.

Hori M, Mori H, Aoki S, Abe O, Masumoto T, Kunimatsu S, Ohtomo K, Kabasawa H, Shiraga N, Araki T. Three-dimensional susceptibility-weighted imaging at 3 T using various image analysis methods in the estimation of **grading intracranial gliomas**. Magn Reson Imaging. 2010 May;28(4):594-8.

Hu J, Yu Y, Juhasz C, Kou Z, Xuan Y, Latif Z, Kudo K, Chugani HT, Haacke EM. MR susceptibility weighted imaging (SWI) complements conventional contrast enhanced T1 weighted MRI in characterizing brain abnormalities of **Sturge-Weber Syndrome**. J Magn Reson Imaging. 2008 Aug;28(2):300-7

Juhasz C, Haacke EM, Hu J, Xuan Y, Makki M, Behen ME, Maqbool M, Muzik O, Chugani DC, Chugani HT. Multimodality imaging of cortical and white matter abnormalities in **sturge-weber syndrome**. AJNR Am J Neuroradiol. 2007 May;28(5):900-6.

Kao HW, Tsai FY, Hasso AN. **Predicting stroke evolution**: comparison of susceptibility-weighted MR imaging with MR perfusion. Eur Radiol. 2012 Jul;22(7):1397-403.

Langkammer C, Schweser F, Krebs N, Deistung A, Goessler W, Scheurer E, Sommer K, Reishofer G, Yen K, Fazekas F, Ropele S, Reichenbach JR. Quantitative susceptibility mapping (**QSM**) as a means to measure **brain iron**? A post mortem validation study. Neuroimage. 2012 Sep;62(3):1593-9.

Lee BC, Vo KD, Kido DK, Mukherjee P, Reichenbach J, Lin W, Yoon MS, Haacke M. MR high-resolution blood oxygenation level-dependent venography of **occult (low-flow) vascular lesions**. AJNR Am J Neuroradiol 1999; 20:1239-1242.

Lee JH, Yang TI, Cho M, Yoon KT, Baik SK, Han YH. Widespread **cerebral cortical mineralization in Wilson's disease** detected by susceptibility-weighted imaging. J Neurol Sci. 2012 Feb 15;313(1-2):54-6.

Li C, Ai B, Li Y, Qi H, Wu L. Susceptibility-weighted imaging in **grading brain astrocytomas**. Eur J Radiol. 2010 Jul;75(1):e81-5.

Li W, Wu B, Liu C. **Quantitative susceptibility mapping of human brain** reflects spatial variation in tissue composition. Neuroimage. 2011 Apr 15;55(4):1645-56.

Lim IA, Faria AV, Li X, Hsu JT, Airan RD, Mori S, van Zijl PC. **Human brain atlas** for automated region of interest selection in quantitative susceptibility mapping: application to determine iron content in deep gray matter structures. Neuroimage. 2013 Nov 15;82:449-69.

Liu T, Eskreis-Winkler S, Schweitzer AD, Chen W, Kaplitt MG, Tsiouris AJ, Wang Y. **Improved subthalamic nucleus depiction with quantitative susceptibility mapping**. Radiology. 2013 Oct;269(1):216-23.

Lu J, Li YH, Li YD, Li MH, Zhao JG, Chen SW. The clinical value of **antiplatelet therapy for patients with hemorrhage after thrombolysis** based on susceptibility-weighted imaging: a prospective pilot study. Eur J Radiol. 2012 Dec;81(12):4094-8.

Lupo JM, Chuang CF, Chang SM, Barani IJ, Jimenez B, Hess CP, Nelson SJ. 7-Tesla susceptibility-weighted imaging to **assess the effects of radiotherapy on normal-appearing brain in patients with glioma**. Int J Radiat Oncol Biol Phys. 2012 Mar 1;82(3):e493-500.

Lupo JM, Essock-Burns E, Molinaro AM, Cha S, Chang SM, Butowski N, Nelson SJ. Using susceptibility-weighted imaging to determine **response to combined anti-angiogenic, cytotoxic, and radiation therapy in patients with glioblastoma multiforme**. *Neuro Oncol*. 2013 Apr;15(4):480-9.

Mittal S, Wu Z, Neelavalli J, Haacke EM. Susceptibility-weighted imaging: technical aspects and **clinical applications**, part 2. *AJNR Am J Neuroradiol*. 2009 Feb;30(2):232-52.

Ouyang HQ, Gong ZJ, Zha YF, Liu CS, Yang ZH. **Splenic siderotic nodules in patients with liver cirrhosis**. *Exp Ther Med*. 2013 Aug;6(2):445-450.

Pinker K, Noebauer-Huhmann IM, Stavrou I, Hoefftberger R, Szomolanyi P, Karanikas G, Weber M, Stadlbauer A, Knosp E, Friedrich K, Trattng S. High-resolution contrast-enhanced, susceptibility-weighted MR imaging at 3T in patients with **brain tumors: correlation with positron-emission tomography and histopathologic findings**. *AJNR Am J Neuroradiol*. 2007 Aug;28(7):1280-6.

Pinker K, Stavrou I, Szomolanyi P, Hoefftberger R, Weber M, Stadlbauer A, Noebauer-Huhmann IM, Knosp E, Trattng S. Improved preoperative evaluation of **cerebral cavernomas** by high-field, high-resolution susceptibility-weighted magnetic resonance imaging at 3 Tesla: comparison with standard (1.5 T) magnetic resonance imaging and correlation with histopathological findings--preliminary results. *Invest Radiol*. 2007 Jun;42(6):346-51.

Radbruch A, Graf M, Kramp L, Wiestler B, Floca R, Bäumer P, Roethke M, Stieltjes B, Schlemmer HP, Heiland S, Bendszus M. **Differentiation of brain metastases** by percentagewise quantification of intratumoral-susceptibility-signals at 3 Tesla. *Eur J Radiol*. 2012 Dec;81(12):4064-8.

Radbruch A, Mucke J, Schweser F, Deistung A, Ringleb PA, Ziener CH, Roethke M, Schlemmer HP, Heiland S, Reichenbach JR, Bendszus M, Rohde S. Comparison of susceptibility weighted imaging and TOF-angiography **for the detection of thrombi in acute stroke**. *PLoS One*. 2013 May 23;8(5):e63459.

Radbruch A, Wiestler B, Kramp L, Lutz K, Bäumer P, Weiler M, Roethke M, Sahm F, Schlemmer HP, Wick W, Heiland S, Bendszus M. **Differentiation of glioblastoma and primary CNS lymphomas** using susceptibility weighted imaging. *Eur J Radiol*. 2013 Mar;82(3):552-6.

Rauscher A, Sedlacik J, Barth M, Mentzel HJ, Reichenbach JR. Magnetic susceptibility-weighted MR **phase imaging of the human brain**. *AJNR Am J Neuroradiol*. 2005 Apr;26(4):736-42.

Rumzan R, Wang JJ, Zeng C, Chen X, Li Y, Luo T, Lv F, Wang ZP, Hou H, Huang F. **Iron deposition in the precentral grey matter in patients with multiple sclerosis**: a quantitative study using susceptibility-weighted imaging. *Eur J Radiol*. 2013 Feb;82(2):e95-9.

Rauscher A, Sedlacik J, Deistung A, Mentzel HJ, Reichenbach JR. Susceptibility weighted imaging: data acquisition, image reconstruction and **clinical applications**. *Z Med Phys*. 2006;16(4):240-50.

Reichenbach JR, Haacke EM. High-resolution BOLD **Venographic imaging: a window into brain function**. *NMR Biomed* 2001;14:453-467.

Reichenbach JR, Jonetz-Mentzel L, Fitzek C, Haacke EM, Kido DK, Lee BCP, Kaiser WA. High-resolution blood oxygen-level dependent **MR venography** (HRBV): a new technique. *Neuroradiology* 2001;43:364–369.

Reichenbach JR, Venkatesan R, Schillinger DJ, Kido DK, Haacke EM. Small vessels in the human brain: **MR venography** with deoxyhemoglobin as an intrinsic contrast agent. *Radiology* 1997; 204:272-277.

Santhosh K, Kesavadas C, Thomas B, Gupta AK, Thamburaj K, Kapilamoorthy TR. Susceptibility weighted imaging: **a new tool in magnetic resonance imaging of stroke**. *Clin Radiol*. 2009 Jan;64(1):74-83

Sehgal V, Delproposito Z, Haacke EM, et al. **Clinical applications of neuroimaging** with susceptibility-weighted imaging. *J Magn Reson Imaging* 2005;22:439-50.

Sehgal V, Delproposito Z, Haddar D, Haacke EM, Sloan AE, Zamorano LJ, Barger G, Hu J, Xu Y, Prabhakaran KP, Elangovan IR, Neelavalli J, Reichenbach JR. Susceptibility-weighted imaging to visualize blood products and **improve tumor contrast** in the study of brain masses. *J Magn Reson Imaging*. 2006 Jul;24(1):41-51.

Solak A, Sahin N, Genç B, Sever AR, Genç M, Sivrikoz ON. Diagnostic value of susceptibility-weighted **imaging of abdominal wall endometriomas** during the cyclic menstrual changes: a preliminary study. *Eur J Radiol*. 2013 Sep;82(9):e411-6.

Spitz G, Maller JJ, Ng A, O'Sullivan R, Ferris NJ, Ponsford JL. Detecting **lesions after traumatic brain injury** using susceptibility weighted imaging: a comparison with fluid-attenuated inversion recovery and correlation with clinical outcome. *J Neurotrauma*. 2013 Dec 15;30(24):2038-50.

Schipper HM. **Neurodegeneration with brain iron accumulation** - clinical syndromes and neuroimaging. *Biochim Biophys Acta*. 2012 Mar;1822(3):350-60.

Tan IL, van Schijndel RA, Pouwels PJW, van Walderveen MAA, Reichenbach JR, Manoliu RA, Barkhof F. **MR venography of multiple sclerosis**. *AJNR Am J Neuroradiol* 2000;21:1039–1042.

Tao R, Zhang J, Dai Y, You Z, Fan Y, Cui J, Wang J. **Characterizing hepatocellular carcinoma** using multi-breath-hold two-dimensional susceptibility-weighted imaging: comparison to conventional liver MRI. *Clin Radiol*. 2012 Dec;67(12):e91-7.

Thomas B, Somasundaram S, Thamburaj K, Kesavadas C, Gupta AK, Bodhey NK, Kapilamoorthy TR. **Clinical applications** of susceptibility weighted MR imaging of the brain – a pictorial review. *Neuroradiology*. 2008 Feb;50(2):105-16.

Tong K, Ashwal S, Holshouser BA, Nickerson J, Wall CJ, Shutter LA, Osterdock RJ, Haacke EM, Kido D. **Diffuse axonal injury in children**: clinical correlation with hemorrhagic lesions. *Ann Neurol* 2004 Jul; 56(1):36-50.

Tong KA, Ashwal S, Holshouser BA, Shutter LA, Herigault G, Haacke EM, Kido DK. **Hemorrhagic shearing lesions** in children and adolescents with posttraumatic diffuse axonal injury: improved detection and initial results. *Radiology*. 2003;22:332-9.

Tong KA, Ashwal S, Obenaus A, Nickerson JP, Kido D, Haacke EM. Susceptibility-weighted MR imaging: a review of **clinical applications in children**. AJNR Am J Neuroradiol. 2008 Jan;29(1):9-17.

Tsai FY, Kao HW, Tsui YK, Hasso AN, Greensite F. Susceptibility weighted imaging and **cerebrovascular disorders**. Neuroradiol J. 2011 Mar 29;24(1):121-7.

Tsai FY, Lee KW, Kao HW, Chen CY. Susceptibility-weighted imaging, an **additional tool to diagnose brain death**: initial experience. Neuroradiol J. 2012 Nov;25(5):505-8.

Tsui YK, Tsai FY, Hasso AN, Greensite F, Nguyen BV. Susceptibility-weighted imaging **for differential diagnosis of cerebral vascular pathology**: a pictorial review. J Neurol Sci. 2009 Dec 15;287(1-2):7-16.

Wakefield JC, Downey K, Kyriazi S, deSouza NM. **New MR techniques in gynecologic cancer**. AJR Am J Roentgenol. 2013 Feb;200(2):249-60.

Wang M, Dai Y, Han Y, Haacke EM, Dai J, Shi D. Susceptibility weighted imaging in **detecting hemorrhage in acute cervical spinal cord injury**. Magn Reson Imaging. 2011 Apr;29(3):365-73.

Wang Y, Butros SR, Shuai X, Dai Y, Chen C, Liu M, Haacke EM, Hu J, Xu H. Different **iron-deposition patterns of multiple system atrophy with predominant parkinsonism and idiopathic Parkinson diseases** demonstrated by phase-corrected susceptibility-weighted imaging. AJNR Am J Neuroradiol. 2012 Feb;33(2):266-73.

Wu J, Tarabishy B, Hu J, Miao Y, Cai Z, Xuan Y, Behen M, Li M, Ye Y, Shoskey R, Haacke EM, Juhász C. **Cortical calcification in Sturge-Weber Syndrome** on MRI-SWI: relation to brain perfusion status and seizure severity. J Magn Reson Imaging. 2011 Oct;34(4):791-8.

Wu Z, Mittal S, Kish K, Yu Y, Hu J, Haacke EM. **Identification of calcification** with MRI using susceptibility-weighted imaging: a case study. J Magn Reson Imaging. 2009 Jan;29(1):177-82.

Xing W, He X, Kassir MA, Chen J, Ding J, Sun J, Hu J, Zhang Z, Haacke EM, Dai Y. **Evaluating hemorrhage in renal cell carcinoma** using susceptibility weighted imaging. PLoS One. 2013;8(2):e57691.

Zeng QS, Kang XS, Li CF, Zhou GY. **Detection of hemorrhagic hypointense foci in radiation injury** region using susceptibility-weighted imaging. Acta Radiol. 2011 Feb 1;52(1):115-9.

Zhang H, Tan Y, Wang XC, Qing JB, Wang L, Wu XF, Zhang L, Liu QW. Susceptibility-weighted imaging: The **value in cerebral astrocytomas grading**. Neurol India. 2013 Jul-Aug;61(4):389-95.

Zhang J, Tao R, You Z, Dai Y, Fan Y, Cui J, Mao Q, Wang J. Gamna-Gandy bodies of the spleen detected with susceptibility weighted imaging: maybe a **new potential non-invasive marker of esophageal varices**. PLoS One. 2013;8(1):e55626.

Zhang J, Zhang Y, Wang J, Cai P, Luo C, Qian Z, Dai Y, Feng H. **Characterizing iron deposition in Parkinson's disease** using susceptibility-weighted imaging: an in vivo MR study. Brain Res. 2010 May 12;1330:124-30.