Susceptibility Weighted Imaging (SWI) of the kidney at 3 T – initial results

Moritz B. Mie[1,*,a], Johanna C. Nissen[2,a], Frank G. Zöllner[1], Melanie Heilmann[1], Stefan O. Schoenberg[2], Henrik J. Michaely[2], Lothar R. Schad[1]

[1] Computer Assisted Clinical Medicine, Medical Faculty Mannheim, Heidelberg University, Germany
[2] Institute of Clinical Radiology and Nuclear Medicine, University Medical Center Mannheim, Heidelberg University, Mannheim, Germany

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Abstract

Susceptibility weighted imaging provides diagnostic information in strokes, hemorrhages, and cerebral tumors and has proven to be a valuable tool in imaging venous vessels in the cerebrum. The SWI principle is based on the weighting of T_2 weighted magnitude images with a phase mask, therewith improving image contrast of veins or neighbouring structures of different susceptibility, in general. T_2* weighted MRI is already used for assessment of kidney function. In this paper, the feasibility of SWI on kidneys was investigated. Translation of SWI from the brain to the kidneys comes along with two main challenges: (i) organ motion due to breathing and (ii) a higher oxygenation level of renal veins compared to the brain. To handle these problems, the acquisition time has been cut down to allow for breath-hold examinations, and different post-processing methods including a new phase mask were investigated to visualize renal veins. Results showed that by a new post-processing strategy SWI contrast was enhanced on average by a factor of 1.33 compared to the standard phase mask. In summary, initial experiences of SWI on the kidneys demonstrated the feasibility. However, further technical developments have to be performed to make this technology applicable in clinical abdominal MRI.*

Suszeptibilitätsgewichtete Bildgebung der Niere bei 3 T – Initiale Ergebnisse

Zusammenfassung

Suszeptibilitätsgewichtete Bildgebung liefert diagnostische Informationen bei Schlaganfällen, Hirnblutungen und Gehirntumoren und hat sich als nützliches Hilfsmittel zur Darstellung venöser Gefäße etabliert. Das SWI-Prinzip basiert auf der Wichtung von T_2-gewichteten Bildern mit einer Phasenmaske, um den Kontrast der Venen oder anderen angrenzenden Strukturen unterschiedlicher Suszeptibilität zu verstärken. T_2*-gewichtete MR-Bildgebung wird bereits zur Beurteilung der Nierenfunktion benutzt. In dieser Arbeit wird die Durchführbarkeit von SWI an Nieren untersucht. Die Übertragung von SWI vom Gehirn zu den Nieren geht mit zwei großen Schwierigkeiten einher: (i) Organbewegung durch Atmung und (ii) ein in der Niere erhöhter Oxygenierungsgrad der venösen Gefäße im Vergleich zum Gehirn. Um diese Probleme zu bewältigen, wurde die Aufnahmezeit reduziert, um Aufnahmen während einer Atemanhaltephase zu ermöglichen, und verschiedene Bildnachverarbeitungsmethoden, u.a. eine neue Phasenmaske, wurden untersucht, um die venösen Gefäße der Niere zu visualisieren. Ergebnisse zeigten, dass diese Strategie im Mittel um den Faktor 1,33 verbesserte suszeptibilitätsgewichtete Kontraste erzeugt*

* Corresponding author. Heidelberg University, Computer Assisted Clinical Medicine, Medical Faculty Mannheim, Theodor-Kutzer-Ufer 1-3, 68167 Mannheim, Germany.

E-mail: moritz.mie@medma.uni-heidelberg.de (M.B. Mie).

[a] Both authors contributed equally.

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im Vergleich zur Standard-Nachverarbeitung. Diese initialen Ergebnisse demonstrieren, dass SWI-Nierenbildgebung prinzipiell möglich ist. Für eine klinische Anwendung müssen jedoch noch weitergehende technische Entwicklungen erfolgen.

Schlüsselwörter: Suszeptibilitätsgewichtete Bildgebung, Niere, MRT, 3T

Introduction

The kidneys play an important role in the control of blood pressure as well as in homeostasis by selectively excreting or retaining various substances [1,2]. There are many diseases leading to an impaired function of the kidney, particularly long standing diabetes mellitus and renal artery stenosis, but also acute and chronic rejection after renal transplantation [2].

T_2* weighted MRI is a tool in the diagnostic work-up of kidney diseases allowing for the assessment of organ function [3,4]. Susceptibility differences can be visualized with susceptibility weighted imaging (SWI) by using also phase information in addition to magnitude images [5,6]. Till now, SWI is applied to the cerebrum, primarily to enhance image contrast of veins [7,8]. Venous vessels show a higher susceptibility difference in comparison to the surrounding tissue due to the high concentration of deoxygenated hemoglobin. Besides mere visualization of venous vessels in the cerebrum [9], SWI has been furthermore applied to the imaging of strokes [10,11], hemorrhages [12], and cerebral tumors [13]. As SWI contrast depends on the fraction of deoxygenated hemoglobin in blood, an indirect assessment of tissue oxygenation would be a further possible application. Hence, after having implemented SWI on normal kidneys in a first step, SWI of renal tumors and assessment of the response to chemotherapy is planned next.

To our knowledge, implementation of SWI on the kidney has not been attempted yet. In comparison to cerebral imaging, in renal imaging different problems have to be solved: On the one hand, one has to cope with respiratory and bulk motion due to peristaltics leading to pronounced artifacts. Therefore, the acquisition time should be as short as possible. On the other hand, the kidney shows different oxygen consumption with a higher oxygen fraction in the venous vessel system than in the cerebral veins. Thus, the susceptibility difference between the venous vessels and the surrounding tissue is not as pronounced as in the brain.

Our aim was to implement SWI on the kidney assuming that through variation of the phase mask even small susceptibility differences become visualizable.

Theory

Depending on the oxygenation level of the blood, the oxy-to-deoxy-hemoglobin ratio changes. Whereas oxyhemoglobin and the surrounding tissue are diamagnetic, deoxyhemoglobin is paramagnetic. Thus, the lower the blood oxygenation level in a vascular network becomes, i.e. the more deoxyhemoglobin is present, the higher the susceptibility differences between vessels and surrounding tissue are [14].

In MRI, this effect is used for imaging as the susceptibility of venous blood in a vascular network creates a susceptibility contrast: In the following, it is assumed that the arterial blood is fully oxygenated. The absolute change of the magnetic susceptibility $\Delta\chi$ consists of three factors: (i) The hematocrit value of the subject Hct, (ii) the susceptibility difference between fully deoxygenated and fully oxygenated blood $\Delta\chi_{do}$, and (iii) the Oxygen Extraction Fraction (OEF), which is the ratio between consumed and delivered oxygen,

$$\Delta\chi = Hct \cdot \Delta\chi_{do} \cdot OEF. \quad (1)$$

Depending on the vessel orientation to the main magnetic field, there are extravascular magnetic field inhomogeneities around the vessel [15,16]. These inhomogeneities in the magnetic field ΔB cause a local phase shift $\Delta\varphi$, which is proportional to the echo time TE,

$$\Delta\varphi = -\gamma \cdot TE \cdot \Delta B, \quad (2)$$

where γ is the gyromagnetic ratio. This local phase shift is the basis of SWI [5]. From the recorded complex-valued MR signals, usually a magnitude image is reconstructed, neglecting any available phase information. In contrast, in SWI, this extra information is used to enhance the corresponding magnitude image by creating a so called phase mask.

Materials and Methods

MR Imaging

MR images were acquired on a 3T whole-body scanner (Tim Trio, Siemens Medical Solutions, Erlangen, Germany) using a 6-element phased-array surface coil in