Improved visualization of cartilage canals using semi-quantitative susceptibility mapping

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Introduction

Recently, visualization of the cartilage canal vessels of epiphyseal growth cartilage was reported using susceptibility weighted imaging (SWI) (1). Superior visualization compared to previous contrast enhanced imaging (2,3) was demonstrated; however, a visualization artifact (doubling, or "splitting" of the vessels along B0 direction) in the SWI approach due to the dipolar phase pattern was also noted. Using a simple phase masking technique, which is the basis of the SWI, results in an artifact in one direction, along or perpendicular to B0, depending on the properties of the phase mask (1,4). The purpose of this study was to evaluate semi-quantitative susceptibility mapping (QSM) (5,6) to resolve the dipolar phase pattern in order to improve visualization of cartilage canal vessels.

Methods

Distal femora of piglets of 1-8 weeks of age were obtained for the study. Imaging was done at 9.4 T, using Agilent VnmrJ3.1 console. The specimens were immersed in perfluoropolyether and imaged with a quadrature volume tranceiver coil (Millipede, Varian NMR Systems, Palo Alto, CA, USA). A 3-D GRE sequence with TR/TE = 40/14 ms, flip angle = 15° and receiver bandwidth = 16 kHz was used. The FOV and matrix size were set up to yield approximately 100 µm isotropic resolution.

To visualize the cartilage canals (1), post processing of the data was done using a standard SWI method according to Haacke et al (7), or using a semi-quantitative approach following Shmueli et al (5). Post-processing was done using MATLAB (version 2012b, The MathWorks, Natick, MA) and Prelude tool of FSL (8). Briefly, in the SWI method, the phase data was unwrapped by homodyne filtering; a negative phase mask was created and applied to the magnitude data multiple times. In the semi-quantitative approach (referred to as sQSM from here on), phase data was masked to the region of interest and unwrapped using Prelude. Slowly varying background fields were estimated and removed adapting the method presented by Rauscher et al (9). The underlying susceptibility distribution (excluding scaling constants, since visualization rather than measuring susceptibility, was the goal, thus the use of the prefix "semi") was calculated as a deconvolution in the k-space (5). To stabilize inversion of the k-space filter, the values of it were truncated as previously described (5). Finally, cartilage canals were visualized in SWI or QSM-processed data using minimum/maximum intensity projections through a 2-mm slab, or by generating a 3-D volume rendering of the entire volume.

Results

As reported previously, the cartilage canals were visualized in the developing distal femur after SWI post-processing (Figures 1bc, 2a). The unwrapped high-pass filtered phase showed the dipolar phase pattern, with negative lobes along B0 (Figure 1d). The same pattern propagated through the phase mask creation into the final SWI data (Figure 1b), more clearly demonstrated in the minimum intensity projection (Figure 1c). The sQSM processing resolved the underlying susceptibility distribution, as shown with inverted gray scale in Figure 1e. A clear advantage for the visualization of the cartilage canals was noted for sQSM processing, as was demonstrated in the minimum intensity projections generated for SWI and sQSM data (Figures 1c and 1f). The 3-D volume renderings further demonstrated the advantage of using sQSM processing (Figure 2).

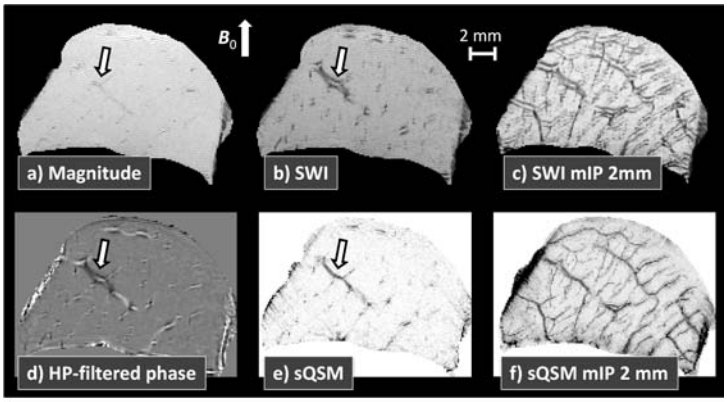

Figure 1. Selected coronal imaging slice of the medial femoral condyle of an 8-week-old piglet. Cartilage canals are faintly seen in magnitude image (a), and filtered phase (d). Canals are more clearly visualized in SWI data (b-c) and further resolved in the sQSM data (e-f).

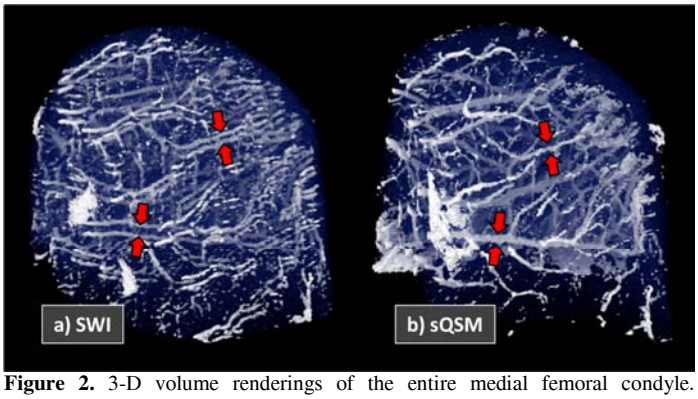

Figure 2. 3-D volume renderings of the entire medial femoral condyle. Apparent doubling of the canals is clearly seen in the SWI data (a), which is resolved in the sQSM data (b). The arrows point to matching canals, highlighting the differences between the post-processing methods.

Discussion and conclusions

In this study, an improved post-processing method of SWI data for visualization of cartilage canals was implemented and compared to previously reported SWI method (1). The results demonstrated a substantial improvement over standard SWI post-processing (4) by using a semi-quantitative approach following Shmueli et al (5). While the sQSM approach discards the actual susceptibility, which could also be important, the end goal of visualizing the vessels within the cartilage canals was reached. Computationally the sQSM processing is only minimally more demanding than SWI post-processing. In fact, the unwrapped phase produced in the SWI post-processing can be used for the susceptibility deconvolution as well, reducing the time required by unwrapping the phase using Prelude (especially for high resolution images). These findings further encourage using SWI, a technique that does not require injection of a contrast agent, as a tool for visualizing cartilage canals in epiphyseal growth cartilage. Implementation of this technique for clinical use would allow evaluation of cartilage canal vasculature in developmental orthopaedic diseases.

References

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Acknowledgments

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