Author: Stomp, W.
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Chapter 5

Opposed-phase gradient echo MR imaging improves visualization of erosions in arthritis and reduces scan time

W Stomp, JL Bloem, AHM van der Helm-van Mil, M Reijnierse

Submitted

Abstract

Objectives

In magnetic resonance imaging for rheumatoid arthritis, demarcating erosions may be hard because of cortical destruction and because bone marrow edema and synovium have similar signal intensity. Opposed-phase gradient echo (OPGE) imaging might improve delineation of the bone-tissue interface.

Materials and Methods

Wrist and MCP joints of fourteen early arthritis patients were imaged on a 1.5T extremity MRI. Coronal T1, T2 fatsat and post-Gd-chelate T1-fatsat as well as OPGE pre- and post-Gd-chelate sequences were obtained. T1-based and OPGE-based image sets were assessed for image quality and scored according to OMERACT RAMRIS score for erosions in consensus by two observers. A reference score was established using all available images.

Results

Image quality, absence of motion artifacts and sharpness were better on OPGE than on T1-weighted images (all scored 5 versus 4 on a 1-5 scale). Homogeneity, signal-to-noise ratio, RAMRIS erosion scores and confidence did not differ between sequences. There was a trend towards higher sensitivity of OPGE images for detection of erosions (85.6% vs 68.0%). Acquisition time was shorter for OPGE (43s vs 3m30s).

Conclusions

The use of OPGE imaging to assess erosions reduces imaging time while providing better image quality. It might increase sensitivity for small erosions compared to T1.

Introduction

Erosions are an important feature of rheumatoid arthritis (RA) and are characterized on magnetic resonance (MR) as sharply marginated bone lesions with a cortical break with typical location and signal characteristics. In healthy bones, the margin of the bone is easily observed, as cortical bone appears dark on all regular MR sequences. At the site of erosion there is no directly observable structure separating medullary bone from the synovial space. In addition, erosions are often surrounded by synovitis at the articular side and bone marrow edema on the side of the bone, which both appear similar on conventional MRI sequences (intermediate signal on T1 and high signal on Gd-chelate enhanced T1). Opposed-phase gradient echo (OPGE) imaging might enhance the visibility of the boundary between synovium and bone marrow by visualizing it as a clear black line. The purpose of this study was to determine the feasibility of OPGE imaging to improve the MR identification of erosions in RA and to shorten acquisition time.

Materials and Methods

MR imaging of the wrist and MCP joints at the most painful side was performed in 14 early arthritis patients on a 1.5 T extremity MR system (General Electric, Wisconsin) using a 100mm quadrature volume transmit and receive coil. The following sequences were acquired, all in the coronal plane for both wrist and MCP joints: T1-weighted fast spin echo (FSE) (repetition time (TR)/echo time (TE) 650/17 ms; acquisition matrix 388 × 288; echo train length (ETL) 2); T2-weighted FSE with frequency selective fat saturation (TR/TE 3000/61.8 ms; acquisition matrix, 300 x 224, ETL 7); spoiled out-of-phase OPGE (TR 250ms, TE 6.7ms, flip angle 70, acquisition matrix 258×160, acquisition time 43s). Gd-chelate contrast agent (gadoteric acid, Guerbet, Paris, France) was administered intravenously at a standard dose of 0.1 mmol/kg. After injection, the OPGE sequence was repeated, as well as a T1-weighted FSE sequence with frequency selective fat saturation (TR/TE 650/17 ms, acquisition matrix 364 × 224, ETL 2). Field-of-view was 100mm for all sequences and 18 slices with a slice thickness of 2mm and a slice gap of 0.2mm were acquired.

Two image sets were prepared: One set consisted of coronal T1-, T2- and T1 Gd-DTPA, the other of OPGE, T2 and Gd-DTPA enhanced OPGE. Two experienced musculoskeletal radiologists evaluated images in consensus, in two session two weeks apart for each image set and in randomized order. Erosions were scored according to OMERACT RAMRIS score on a 0-9 scale for each location. In a third session, a reference score was established by using all available images to compare the other scores against. Image quality was assessed on several points (overall image quality, homogeneity, absence of movement artifacts, signal-to-noise ratio and sharpness) on a 1-5 scale for the T1-FSE and OPGE sequences specifically, as well as rater confidence in the accuracy of the erosion score.

Erosions and image quality scores were compared using Wilcoxon signed rank test. Test characteristics were calculated comparing T1FSE and OPGE-based scores to the reference score. $P<0.05$ was considered significant. The study was approved by the institutional review board and all patients provided their written informed consent.

Table 1. Image quality and erosion scores

MR sequence:	T1FSE	OPGE	P-value	Reference score
Overall image quality	4 (4-4)	5 (5-5)	.005	
- Homogeneity	5 (4-5)	5 (5-5)	.066	
- Absence of movement artifacts	4 (3-5)	5 (5-5)	.006	
- Signal-to-noise ratio	5 (5-5)	5 (5-5)	1.00	
- Sharpness	4 (3-5)	5 (5-5)	.006	
Total erosion score	3 (0-11)	5 (3-14)	.366	4.5 (3-13.25)
Rater Confidence	4 (4-5)	5 (4-5)	1.00	

Grading of image quality features (1=worst, 5=best), erosion scores and rater confidence. Values are presented as median (interquartile range). The reference score is a score obtained by assessing all available images. OPGE: out of phase gradient echo.

Results

Image quality, absence of movement artifacts and sharpness were better on OPGE images than on T1FSE images (Table 1). Homogeneity, signal-to-noise ratio, RAMRIS erosion scores and rater confidence did not differ significantly between sequences. According to the consensus reference score, erosions were present (score >=1) in 97 out of 322 assessed bones. Compared with the reference score, sensitivity of T1 was 68.0% (95% CI 57.7-76.9%), specificity 98.7% (95% CI 95.8-99.7%), NPV 87.7% (95% CI 82.9-91.4%) and PPV 95.7% (95% CI 87.0-98.9%). Sensitivity of OPGE was 85.6% (95% CI 76.6-91.6%), specificity 94.2% (95% CI 90.1-96.8%), NPV 93.8% (95% CI 89.6-96.4%) and PPV 86.5% (95% CI 77.6-92.3%).

Discussion

Our results show that OPGE imaging is feasible for the depiction of erosions and has several distinct advantages. It provides better delineation of the bone marrow-synovial interface than T1FSE images and the technique is easily applicable, fast, with reproducible high quality. In addition, erosion detection based on OMERACT RAMRIS scores is not significantly different between T1FSE and OPGE series.

The OMERACT group has published definitions of joint pathologies observed on MR in RA. Erosions are defined as sharply marginated bone lesions, with juxtaarticular localization and typical signal characteristics, visible in 2 planes with a cortical break seen in at least one plane.[1] It can, despite the clear definition, sometimes be difficult to assess the exact extent of erosions, because the lack of a cortical margin at the site of erosion makes it hard to determine the boundary between synovium and bone marrow. OPGE might enhance the visibility of this transition by visualizing it as a clear black line (Figure 1).

OPGE imaging relies on the fact that protons in fat and water environments resonate at slightly different frequencies. By choosing a specific, field strength dependent, echo time at which fat and water signals are exactly 180 degrees out of phase, fat and water signals

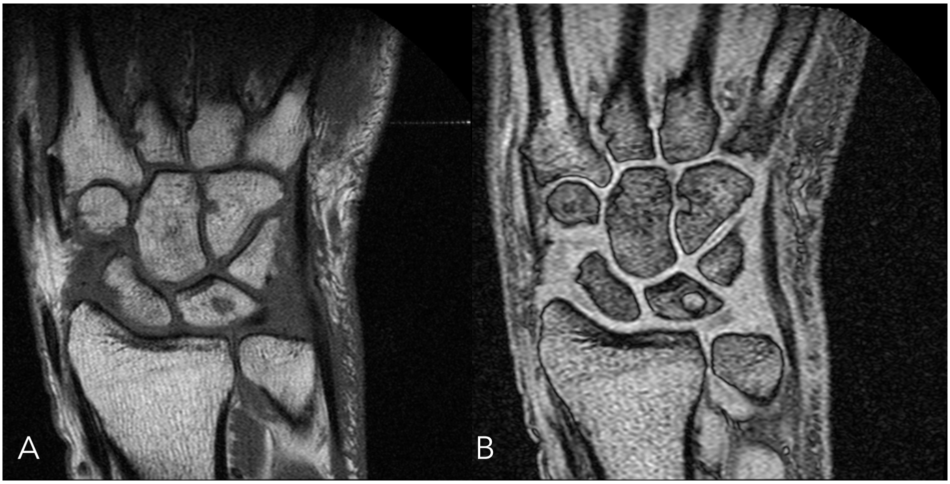

Figure 1. Example showing the improved delineation of erosions of the hamate and lunate bone (cortical break not shown here but visible in different slide) in the wrist on out-of-phase images (b) as compared to T1-weighted images (a).

within the same voxel cancel each other out resulting in reduced signal intensity relative to conventional images.[2] The appearance of OPGE images is described as an Indian-ink effect: a prominent black line is visible at the interface between fat and water. Signal loss is higher in voxels with equal signal contribution from fat and water and is less in voxels that contain either fat or water.

As demonstrated, OPGE clearly demarcates erosions. On this sequence both synovitis (as well as synovial hypertrophy and hydrops) and normal bone marrow have high signal intensity due to their homogeneous water and fat content respectively (areas of bone marrow edema may appear darker due to mixed water/fat content), but the interface between bone marrow and synovium/synovial fluid is always clearly visible as a dark rim. Additionally this sequence has the advantage that it can be acquired in a very short amount of time. With an echo time of 6.7ms, images were acquired in just 43s, which is much shorter than regular T1-weighted FSE sequences, which typically take approximately 3 minutes. Due to the short imaging time, out-of-phase imaging is also much less susceptible to patient motion artifacts, which occur frequently in patients with painful joints being imaged (Figure 2).

A limitation of the current study is that erosions were only assessed in one plane, while RAMRIS formally requires visualization in at least two planes. This likely does not affect results as this was true for both T1FSE and OPGE. Furthermore, an ideal assessment would compare in and out of phase T1 gradient echo images and pre- and post-Gd-chelate OPGE images to find the optimal sequences to use. A strength but also potential limitation might be the improved visualization of small erosions, as by accentuating normal bone indentations this may lead to over-reading. Therefore it is important to be familiar with normal anatomy and anatomic variations, such as ligament insertions and small blood vessels, which may mimic erosions.

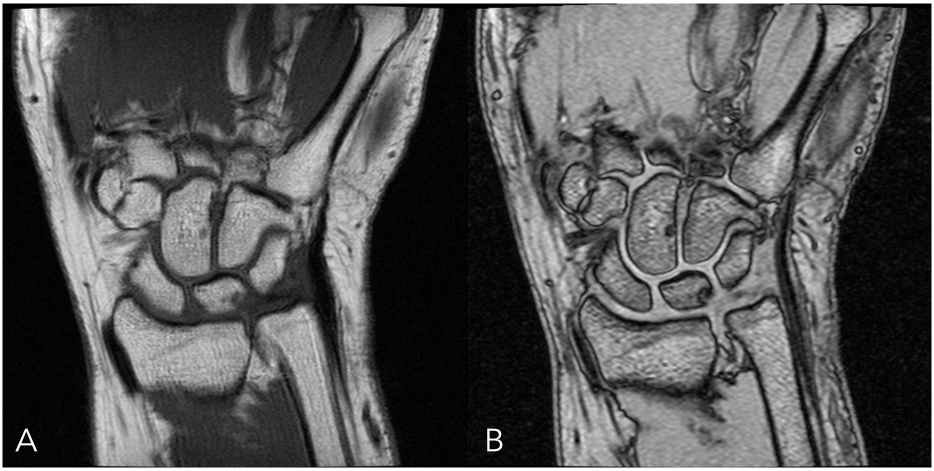

Figure 2. Artifacts due to patient movement observed on T1-weighted scan (a), but not on out-of-phase scan (b). Erosions are visible of the capitate and lunate bone.

Conclusion

OPGE imaging is feasible for the depiction of erosions. It reduces acquisition time and improves image quality, while it might improve sensitivity for small erosions.

References

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