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Motion correction improves image quality of dGEMRIC in finger joints

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ABSTRACT

Purpose: To assess motion artifacts in dGEMRIC of finger joints and to evaluate the effectiveness of motion correction.
Materials and methods: In 40 subjects (26 patients with finger arthritis and 14 healthy volunteers) dGEMRIC of metacarpophalangeal joint II was performed. Imaging used a dual flip angle approach (TE 3.72 ms, TR 15 ms, flip angles 5° and 26°). Two sets of T1 maps were calculated for dGEMRIC analysis from the imaging data for each subject: one with and one without motion correction. To compare image quality, visual grading analysis and precision of dGEMRIC measurement of both dGEMRIC maps for each case were evaluated.
Results: Motion artifacts were present in 82% (33/40) of uncorrected dGEMRIC maps. Motion artifacts were graded as severe or as rendering evaluation impossible in 43% (17/40) of uncorrected dGEMRIC maps. Motion corrected maps showed significantly less motion artifacts ($P < 0.001$) and were graded as evaluable in 97% (39/40) of cases. Precision was significantly higher in motion corrected images (coefficient of variation (CV = .176 ± .077), compared to uncorrected images (CV .445 ± .347) ($P < .001$). Motion corrected dGERMIC was different in volunteers and patients ($P = .044$), whereas uncorrected dGEMRIC was not ($P = .234$).
Conclusion: Motion correction improves image quality, dGEMRIC measurement precision and diagnostic performance in dGEMRIC of finger joints.

1. Introduction

MRI plays an increasingly important role in the diagnosis and treatment monitoring of finger and hand arthritis [1]. The ability of dGEMRIC to non-invasively measure cartilage degradation, demonstrated in prior studies in vitro [2], as well as in vivo at the hip [3], knee [4] and ankle [5], lead to its application in hand and finger arthritis [6].

dGEMRIC exploits the fact, that a higher proportion of Gd^{2-} accumulates by diffusion into degenerated cartilage depleted of negatively charged glycosaminoglycanes, leading to lower T1 values [7]. All imaging protocols for dGEMRIC rely on a parameter map, representing the T1 value (dGEMRIC index) of each pixel calculated from a number (at least two) of consecutive images with different inversion times or flip angles, depending on the T1 mapping approach [8]. Any imaging technique relying on consecutively acquired single scans is subject to motion artifacts arising from patient movement during the acquisition process. In diverse imaging methods like in functional magnetic resonance imaging (fMRI) and dynamic MRI, mathematical motion correction techniques are established to improve the quality of the resulting parameter images [9–12].

Therefore, in the present study assessed motion artifacts in dGEMRIC of finger joints and if they can be reduced with mathematical motion correction.

2. Materials and methods

2.1. Patients

This study was approved by the institutional review board and all patients and volunteers provided written informed consent.

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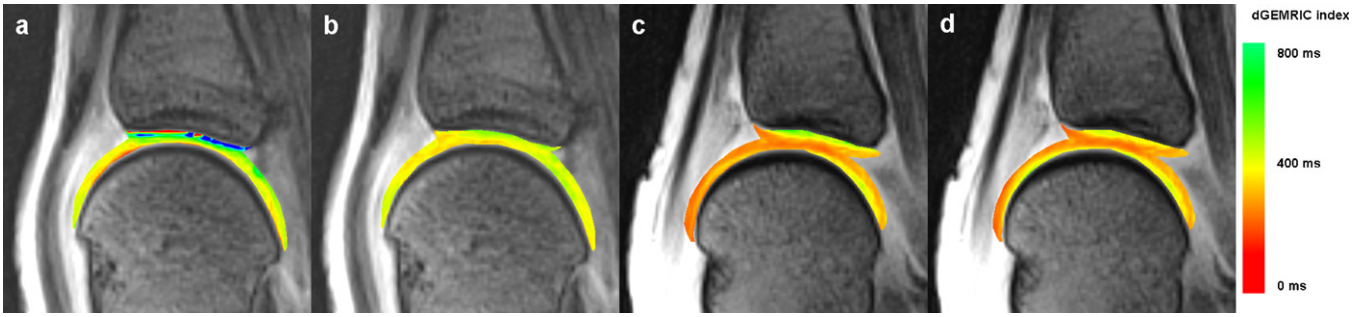

Fig. 1. ROI measurements. (a) Gradient echo image with a flip angle of 5° used as anatomical reference with dGEMRIC ROI from uncorrected colour-coded T1 map overlay of a volunteer (female, 58 years old). Severe motion artifacts are present in the ROI. (VGA 4) (b) Same image overlaid with same ROI from motion corrected T1 map. Motion artifacts are reduced. (c) Uncorrected colour-coded T1 map (dGEMRIC map) of a patient (female, 68 years old). No motion artifacts are present (VGA 1). (d) Motion corrected colour-coded T1 map, dGEMRIC values are not changed by motion correction.

dGEMRIC was performed prospectively in 26 patients with finger arthritis (20 women, six men, mean age 54 years, range 18–77) and 14 healthy volunteers (11 women, three men, mean age 52 years, range 30–66). A total of 40 subjects were included in the study. The patient group consisted of 19 patients with rheumatoid arthritis fulfilling the 2010 American College of Rheumatology classification for RA [13] and of seven patients with hand OA according to the revised criteria for the classification of OA [14]. Exclusion criteria were claustrophobia, pacemakers, renal insufficiency and large metallic implants.

2.2. Imaging protocol

Images of each subject were acquired at a 3-T MR-scanner (Magnetom Trio, Siemens, Erlangen, Germany). The subjects were prone positioned with the hand extended overhead, palm down. The individuals were instructed to try to prevent any upper limb movements. No movements between acquisitions were allowed. One 4 cm loop coil was fixed on the palmar, the other coil on the dorsal side of MCP II. T1 mapping followed a dual flip angle approach [15]. A 40 min delay after intravenous administration of 0.4 ml/kg body weight of gadolinium contrast agent (Magnevist; Schering AG, Berlin, Germany) was kept [15]. TE was 3.72 ms, TR was 15 ms. Flip angles were 5° and 26°, slice thickness was 2 mm and the FOV was 73 × 90 mm, acquisition time was 2:25 min. A matrix of 312 × 384 was used, yielding an in-plane resolution of 233 μm. 22 sagittal slices were positioned orthogonal to the joint spaces.

2.3. Image processing

The image data were transferred to an external workstation running Windows XP® (Microsoft®, Redmond, WA). All image processing was performed using the software STROKETOOL (http://www.digitalimagesolutions.de, Frechen, Germany).

To correct for patient movement between the measurements using different flip angles, an image registration method based on least square measure was applied [16,17]. The motion correction algorithm implemented in the software runs without user interaction.

T1 maps were calculated from the motion corrected images (dGEMRICmoco) as well as from the uncorrected images (dGEMRICnon-moco). In concordance with the literature, T1 is referred to as dGEMRIC index in this context. dGEMRIC index parameter images were calculated using the relation:

$$T1(x,y,z) = \frac{\mathrm{TR}}{\ln\left[\frac{\sin(\alpha_1)\cos(\alpha_2) - Q(x,y,z)\sin(\alpha_2)\cos(\alpha_1)}{\sin(\alpha_1) - Q(x,y,z)\sin(\alpha_2)}\right]} \quad \text{(a)}$$

where

$$Q(x,y,z) = \frac{S_1(x,y,z)}{S_2(x,y,z)} \quad \text{(b)}$$

and $S_1(x,y,z)$, $S_2(x,y,z)$ are the pixel intensities corresponding to the different images acquired with the flip angles 5° and 26° [15,18].

2.4. Image analysis

Objective and subjective measurements of image quality were performed to assess value of image correction. dGEMRIC index measurement precision served as objective measure of image quality. For this, the images were transferred to an external workstation (Leonardo, Siemens, Erlangen, Germany). The images acquired with a flip angle of 5° served as anatomical reference for both, dGEMRICnon-moco and dGEMRICmoco. This was possible, since this image had been left unaltered and only the image acquired with a flip angle of 26° had been modified during the motion correction process, i.e., the image with the 5° flip angle was identical for dGEMRICnon-moco and dGEMRICmoco. ROIs were drawn to include the phalangeal and the metacarpal cartilage of MCP II in the same slice. The ROI was then copied and pasted into the dGEMRICnon-moco and dGEMRICmoco maps (Fig. 1).

Mean dGEMRICnon-moco and dGEMRICmoco index and standard deviation (SD) were recorded. The coefficient of variation (CV) was calculated to assess dGEMRIC measurement precision following formula (c):

$$\mathrm{CV} = \frac{\mathrm{SD\ dGEMRIC}}{\mathrm{mean\ dGEMRIC\ index}} \quad \text{(c)}$$

For measurement of subjective image quality dGEMRIC map visual grading analysis (VGA) was performed. For this, the image acquired with a flip angle of 5° and the corresponding dGEMRICnon-moco and dGEMRICmoco maps were presented in random order to two blinded readers (blinded for review). VGA used a qualitatively ranked 4-point scale (Fig. 2) and was assessed in consensus by the two reviewers. Since dGEMRIC maps are specifically generated for ROI analysis, the possibility to perform ROI analysis was defined as the feature discriminating rank 1–4.

2.5. Statistical analysis

SPSS (Version 18, SPSS, Chicago, Illinois) was used for statistical analysis. A Wilcoxon matched-pairs signed rank test was used to compare dGEMRIC values, CV and VGA for dGEMRICnon-moco and dGEMRICmoco. Chi-squared test was used to test for difference in gender distribution between patients and controls. Correlations were calculated with Spearman-Rho. T1 dGEMRIC values were compared between groups using Wilcoxon–Mann–Whitney test. A P-value less than 0.05 was considered significant.