Three-dimensional image co-registration of mono- and multinuclear MRI data of articular cartilage

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TARGET AUDIENCE: Researchers interested in exploring multiple contrast and/or relaxation parameters at subregions of articular surfaces.

PURPOSE: To present preliminary results using a three-dimensional image coregistration tool, enabling accurate analysis of different quantitative MRI parameters at subregions of articular surfaces.

METHODS: The image coregistration tool has been programmed using MATLAB (2013b, Mathworks, Natick, MA). It utilizes Demon algorithm (implementation based on package created by D-J Kroon) [1] which performs image coregistration in two phases. First, affine coregistration is performed. Subsequently, free form deformation fields are calculated in three steps, first using interpolated matrix size with ¼ of full resolution, then another matrix with size of ½ of full resolution and finally the original full resolution matrix. The iteration loop is terminated if the maximum number of iterations is exceeded (80 for affine and 50 for free form transformation), the number of transform parameters fall below the determined limit, when the optimization function of the free form algorithm is satisfied, or when further iterations do not cause any transform parameter to change even if the limits are not yet met. With the current setup, calculation time for coregistration one image set to another, is 40-60 minutes, depending on image properties.
All images were obtained from the same subject. To demonstrate different factors affecting the quality of coregistered images, DESS images at three different field strengths with best reasonable isotropic resolution (1.5T: 0.8mm; 3T: 0.5mm; 7T: 0.4mm; Siemens Healthcare, Erlangen, Germany). In addition, DESS series acquired at 3T with varying orientation and two contrasts from T2 mapping data (acquired at 3T, in-plane resolution 0.4mm, slice thickness 2mm, TR 1s, TE's 14ms and 70ms), and Na images acquired at 7T were used. A three-dimensional grid and the Jacobian for the free form transformation were used to qualitatively evaluate the accuracy of coregistration.

RESULTS AND DISCUSSION: Image properties and image processing strategies affecting the quality of the coregistration are discussed below.
Resolution. Coregistration between image sets with similar contrast but different isotropic resolution can be successfully performed (Fig 1A-B). However, the larger the difference in the resolution, more there are slight intensity differences between transformed and reference images.
Contrast. T2 mapping data with short TE can be reliably coregistered. Representative slice from the dataset is presented in Fig 2A. The 3D grid transformation and Jacobian for free form transformation is shown in Fig 2B.
Slice orientation. When coregistering images with similar contrast, even large rotations between images resulted in good coregistration (Fig 3A). The 3D deformation grid and Jacobian for that transformation are displayed in Fig 3B. T2 and DESS images with small rotation angles could be reliably coregistered. However, even small rotation angles can be seen in transformed images as stripe pattern, as seen in Fig 2A. This is due to different slice thickness.
Edge detection prior to coregistration. Extracting edges from both image sets and coregistering them will decrease calculation time approximately 75%. When applying MATLAB's 'canny' function to images a reliable transformation can be performed between images of equal contrast and resolution. However, this will affect the quality of the transformation between T2 and DESS images so drastically that this strategy has been rejected.
Cropping prior to coregistration. Limiting transformation to center part of image will decrease computer memory usage by 40% and calculation time by 60%. The accuracy of transformation was significantly improved. If T2 dataset was cropped too anteriorly, transformation was still reliable at applicable area (Fig 4A), but too posterior cropping led to failure (Fig 4B).
Interpolation to match resolution. T2 image set with more coarse resolution is interpolated to match the resolution of the DESS image set. The closest match for each T2 slice is recorded, and additional slices are added with constant distance to match the number of slices. Nearest neighbor interpolation is used. Cubic interpolation provides smoother transitions between adjacent transformed images but also causes ghosting artifact.
As additional examples, CEST and Na images coregistered with DESS images are shown in Fig 5A and 5B, respectively. For Na images, only affine transformation was applied, as the free form transformation could not minimize the optimization function, most probably due to large difference in SNR and resolution between DESS and Na images.

CONCLUSION: By choosing transformation parameters and image processing strategies carefully, reliable coregistration between image sets with different contrasts and resolutions can be achieved. This will greatly improve the localization of regions of interest, especially when applied together with (semi)automatic segmentation using the ideal image contrast and resolution.

REFERENCES
[1] Kroon, D.J. and Slump, C.H. (2009) *MRI Modality transformation in demon registration.* In: IEEE International Symposium on Biomedical Imaging: From Nano to Macro, ISBI '09, 28 Jun - 01 Jul 2009, Boston, MA. pp. 963-966.IEEE Signal Processing Society. ISSN 1945-7936 ISBN 978-1-4244-3931-7

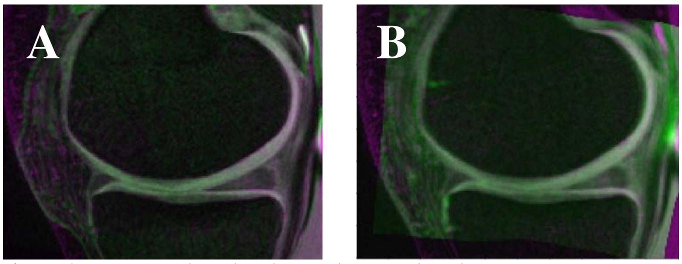

Figure 1. Representative slices illustrating coregistration between A) DESS images acquired at 7T and 3T, B) DESS images acquired at 7T and 1.5T. Green and purple colors denote higher or lower intensity value, respectively in transformed image as compared to the reference image.

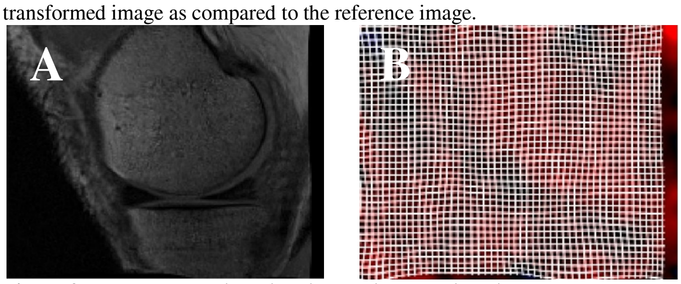

Figure 2. A) Representative slices illustrating coregistration between DESS and T2 mapping images (contrast with echo time of 14 ms) acquired at 3T, B) 3D grid and Jacobian for transformation.

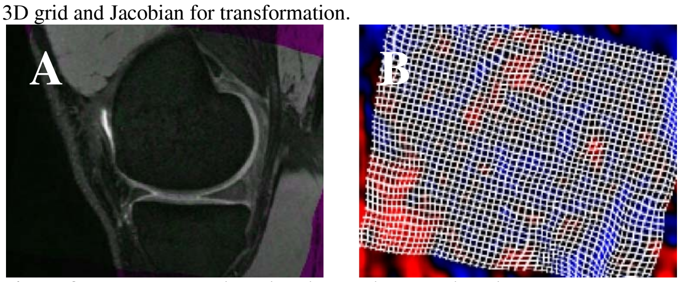

Figure 3. A) Representative slices illustrating coregistration between DESS images acquired at 3T with different slice orientation, B) 3D grid and Jacobian for transformation.

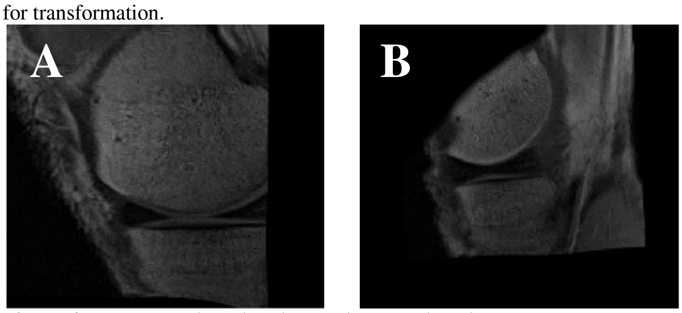

Figure 4. Representative slices illustrating coregistration between DESS and T2 mapping images acquired at 3T with T2 images cropped too A) anteriorly, B) posteriorly.

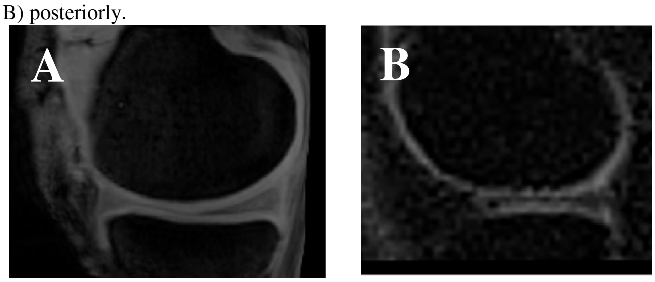

Figure 5. Representative slices illustrating coregistration between DESS and A) CEST map and B) Na image acquired at 7T.