

Prospective Image Registration for Automated Scan Prescription of Follow-up Knee Images

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Introduction

Consistent scan prescription for MRI of the knee is very important for accurate comparison of images in a longitudinal study. For example, when imaging cartilage in osteoarthritis at different time points, follow-up images acquired at the same exact orientation as baseline images would enhance the precision of measurements such as cartilage thickness, cartilage volume, and T_2 relaxation measurements. However, consistent scan region selection is difficult due to the complex shape of the distal femur. Techniques to improve knee image alignment precision by adjusting scanning parameters prior to image acquisition have been previously reported [1]. These techniques generally use probabilistic atlases and segmentation of certain anatomical landmarks in order to align and register images. Therefore they are limited either by the population being represented by the atlas, or by the complexity of identifying landmarks. We propose a novel method for registering knee images using a mutual information registration algorithm [2] to align images in a baseline and follow-up exam. The output of the registration algorithm, three translations and three Euler angles, is then used to redefine the region to be imaged and acquire an identical oblique imaging volume in the follow-up exam as in the baseline. This algorithm is robust to articulation of the knee and anatomical abnormalities due to disease (e.g. osteophytes). We have incorporated this approach in a clinical MR system and have demonstrated its utility in automatically obtaining consistent scan regions between baseline and follow-up examinations, thus improving the precision of quantitative evaluation of cartilage.

Methods

Registration Method: The registration method requires two inputs: a baseline and a follow-up low-resolution fat suppressed SPGR ($0.62 \times 0.62 \times 1 \text{ mm}^3$) image. First, the registration technique identifies a region containing the distal femur by identifying the largest connected component in the anterior side of the baseline image. This region is then used to calculate the similarity measure for image registration and ensures that the registration is only performed on the distal femur and is not affected by the proximal tibia or soft tissues. The output of a mutual information registration algorithm, three translations and three Euler angles, is then input into a modified pulse sequence to redefine the region to be imaged and thus acquire an identical high-resolution oblique imaging volume in the follow-up exam as in the baseline.

MR Imaging: Sagittal images of the knee of 5 volunteers (3 female, 2 male, mean age = 36.16 ± 10.26 years) were acquired on a 3T GE Signa MRI scanner using a 8 channel phase array knee coil. Subjects had a range of cartilage quality, from normal to severe degeneration and osteophytes. Three baseline scans were obtained. The first baseline scan was a low-resolution fat suppressed 3D SPGR sequence (matrix 160×160 , FOV = 16 cm, slice thickness = 1 mm, time = ~2min) acquired for the image registration. The second baseline scan was a high-resolution fat suppressed 3D SPGR sequence (matrix 512×512 , FOV = 16 cm, slice thickness = 1 mm, time = ~10min) acquired for cartilage morphometry. The final baseline scan was a 3D T_2 mapping sequence (matrix 256×128 , slice thickness = 4 mm, four different images acquired with TE = 4.1/14.5/25/45.9 ms, time = ~7min) obtained using an acquisition protocol based on a 3D SPGR sequence, as previously reported [3] which was acquired to access the biochemical composition of the cartilage. The volunteer was then removed from the scanner and repositioned for the follow-up scan where 5 follow-up scans were obtained. The first follow-up scan was a low-resolution fat suppressed SPGR acquired with the same protocol as in the first baseline scan. Using the mutual information based registration method, the low-resolution baseline and follow-up scans were registered. The registration provided the translation and rotation parameters for the definition of an oblique follow-up scan. The next two follow-up scans were acquired with the same parameters as the last two baseline scans except for input parameters from the registration. The final two follow-up scans were also acquired with the same parameters as the last two baseline scans but required a manual scan prescription.

Post Processing: T_2 -maps were computed on a pixel-by-pixel basis from the T_2 mapping sequence based on the following equation: $S(TE) \propto \exp(TE/T_2)$. Five cartilage compartments were segmented semi-automatically in the SPGR images using a spline-based, in-house developed program: Medial/Lateral Femur Condyle (MFC/LFC), Medial/Lateral Tibia (MT/LT) and Patella (P). Cartilage thickness, cartilage volume, and average T_2 relaxation was determined for each compartment. The coefficient of variation (CV) was determined for baseline and follow-up images with and without registration to quantify the improvement in measurement precision.

Results

Figure 1 visually demonstrates an improvement in image alignment between baseline and follow-up images with registration. On average the CV for cartilage thickness, volume, and T_2 relaxation was lower with registration (Tables 1-3). T_2 relaxation measurements were specifically affected for the medial tibia where the cartilage is thin and partial volume effects prevail.

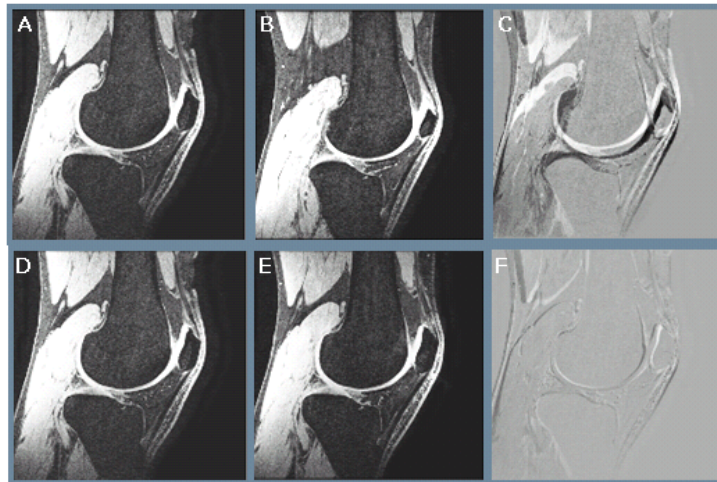


Table 1. Coefficient of Variation for Cartilage Thickness

	LFC	LT	MFC	MT	P
Without Registration	3.19%	4.58%	3.16%	5.78%	2.12%
With Registration	4.02%	4.45%	2.23%	5.12%	1.48%

Table 2. Coefficient of Variation for Cartilage Volume

	LFC	LT	MFC	MT	P
Without Registration	10.21%	6.13%	8.29%	10.06%	1.36%
With Registration	3.51%	3.23%	5.63%	6.45%	2.89%

Table 3. Coefficient of Variation for T_2 Relaxation Measurements

	LFC	LT	MFC	MT	P
Without Registration	2.60%	3.10%	7.46%	11.34%	2.32%
With Registration	1.50%	3.53%	5.94%	5.76%	3.24%

Figure 1 (left). Comparison of baseline images to follow-up with and without registration. (a & d) high-resolution baseline SPGR (b) high-resolution follow-up without registration (c) subtraction of baseline from follow-up without registration (e) high-resolution follow-up with registration (f) subtraction of baseline from follow-up with registration

Discussion

The study of the progression of a disease or the efficacy of a treatment based on knee MRI requires the proper analysis of corresponding regions of interest in the baseline and follow-up images. In this work, we have demonstrated the feasibility of using a mutual information based method to register MR images of the knee without segmentation and automatically determine the follow-up scan prescription. Results suggest that automatic scan prescription will improve the accuracy of cartilage morphologic and T_2 relaxation measurements in longitudinal studies.

References

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