Tensor based morphometry to evaluate longitudinal changes in the femoral cartilage of subjects with osteoarthritis: Data from the Osteoarthritis Initiative (OAI).

Uyen Hoang[1] and Usha Sinha[2]
[1]Bio-informatics, SDSU, San Diego, CA, United States, [2]Physics, SDSU, San Diego, CA, United States

Target Audience: MSK Radiologists (focus on cartilage), Researchers (Quantitative cartilage mapping, image processing)

Purpose: Osteoarthritis is a complex disease and objective documentation of response to treatment is challenging. Recent advances in therapies underline the need for non-invasive monitoring. Cartilage loss with disease progression is small and localized to sub regions of the cartilage, making detection challenging [1,2]. The aim is to map the deformation (Jacobian) of femoral cartilage in a longitudinal study (baseline and 12 mo.) to identify subtle and localized interval changes.

Methods: MR high resolution image volumes of 5 subjects from the Osteoarthritis Initiative (http://www.oai.ucsf.edu/)**;** subject OAI status is provided in Table 1. All subjects were from the subset of OAI data which included segmentation of the cartilage from the high resolution images of longitudinal studies. The segmented cartilage volumes for each subject were first aligned using a rigid transformation to map the baseline to the 12 month volume to correct for position differences. An elastic registration modified for this proposal (see above) will be used to warp the baseline to the follow-up image volumes. This non-linear registration yields a 3D deformation field, defined at each voxel, which maps the spatial locations in the baseline to the corresponding voxel in the follow-up. The registration algorithm computes the transformation iteratively

$$u_{n+1} = G_\sigma \otimes \left(u_n + G_\sigma \otimes \frac{1}{2} \left[\frac{C(T-S)\|\nabla S\|\|\nabla T\|}{(\|\nabla T\|^2 + \|\nabla S\|^2)(\|\nabla S\|^2 + \|\nabla T\|^2 + 2(T-S)^2)} \nabla S \right] \right)$$ [1]

Patient	BaseLine	12 mo
1,L	(2,1,0)	(2,1,0)
2,L	(3,2,0)	(3,2.2,0)
3,R	(1,0,0)	(1,0,0)
4,R	(3,2,0)	(4,3,0)
5,L	(4,3,0)	(4,3,0)

Table1: Subject status Each subject has (patient number, knee (L or R)) and (KL score, Joint Space Narrowing, Medial, Joint Space Narrowing, Lateral)

u_{n+1} is the correction vector field at iteration n+1, Gσ is a Gaussian filter with variance σ, $\otimes$ denotes convolution, C is a scaling factor and T and S are the target and transformed image intensities respectively. The algorithm estimates the displacement, u(q), that maps a voxel at location (q) in T (the target image) to the corresponding anatomical location in S (the subject's transformed image). The algorithm is implemented hierarchically and to preserve the morphology, deformation fields U(q), given by q+u(q), are computed from both the forward and backward transformations. For each subject, a local tissue growth/atrophy map was obtained by calculating the local Jacobian (Jac) determinant (i.e., "expansion factor") of the deformation field, which measures progressive volume contraction (Jacobian < 1) or volume expansion (Jacobian > 1). The Jacobian was calculated as the determinant of the spatial derivatives of the deformation vector.

Results : The deformation fields of baseline to later time point in all five subjects is shown in 3D with the Jacobian values superposed on the later time point volume. Black pixels within the cartilage volume indicate regions where there is no cartilage in the later time point volume. The colormap (Fig. 1) was maintained consistently between all subjects (by applying a normalization) so that comparisons are meaningful (Jac<1 →later time point voxel had to contract to match a corresponding voxel in the baseline (baseline thicker) and Jac>1 →later time point voxel had to expand to match a corresponding voxel in the baseline (baseline thinner)).
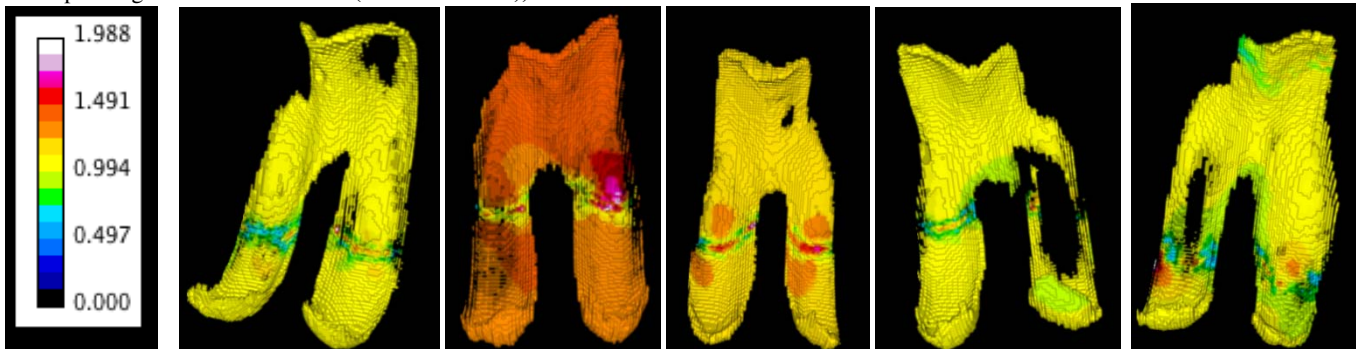

Figure 1: L→R: color map, Subject 1-5: 3D femoral cartilage of later time point overlaid with Jac that represents changes from baseline. Yellow~ no change.

Discussion and Conclusions: Interval changes can be readily visualized on the Jacobian maps. Predominantly the changes indicate a Jac < 1 indicating that the later time point cartilage contracted in these regions compared to the baseline image volumes. Subject 1 with KG score of 2 and no interval changes in (KG, JSM, JSL) shows small or no interval changes in Jac; localized regions that show Jac < 1 may indicate cartilage thickness decrease in the later time-point. Subject 2 with a KG score of 3 and an interval change in JSM from 2 to 2.2 showed the maximum overall increase in cartilage volume with cartilage loss in the weight-bearing region. Subject 3 with a KG score of 1 and no interval changes in (KG, JSM, JSL) shows localized cartilage decreases in the later-time point volume; these are in the weight bearing regions. Subject 4 which had a KG score change from 3 to 4, shows localized loss in later-time point volume and a large region of total cartilage loss was seen. Since there is no Jacobian displayed for areas of no cartilage, interval changes in these areas are not visualized. Subject 5 with a KG score of 4 but no interval changes in (KG, JSM, JSL) showed very localized thinning in addition to complete loss of cartilage in the lateral side.

References:

[1] Eckstein F et al. Nat Rev Rheumatol. 2012;8:622-30. [2] Iranpour-Boroujeni T et al. Osteoarthritis Cartilage. 2011;19:309-14.