Nonrigid registration for the longitudinal analysis of micro-CT bone datasets

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Aims

Micro-CT is an established tool to evaluate the bone architecture in small animals. Especially in-vivo micro-CT is very popular, as it allows longitudinal (i.e. over time) follow-up of the evolution in the same animal. This way, changes in the bone structure over time can be assessed. Usually, bone parameters are measured separately in the different images. To be comparable, a similar location is selected in each image using an anatomical descripition (e.g. '150 μm proximal to the distal growth plate of the femur').
Several authors have proposed to use automated image registration to improve longitudinal analysis of the micro-CT data. Waarsing *etal* [1] use rigid registration to detect and visualize changes in the local bone architecture and individual trabeculae over time. More recently, Nishiyama *etal* [2] have shown that the reproducibility of bone measurements is improved when image registration is used to ensure exactly the same region of interest is chosen in all images.

Aims

Within this article, we evaluate the use of nonrigid or deformable registration for longitudinal bone analysis. Although the bone is a rigid structure, growth and other subtle changes violate this. In [1] this problem is countered e.g. by applying a different rigid transformation to the epiphyseal and metaphyseal area.

Method

Two female mice (OVX and SHAM) were imaged twice: at day 0 and at day 28. Imaging was performed using a Skyscan 1076 micro-CT scanner. Reconstructed images counted 1000 x 1000 x 2019 voxels with a voxelsize of 8.75 micrometer. For the OVX mouse, the ovaries were surgically removed.
Starting from an initial manual alignment, images were rigidly registered using MIRIT [3], an affine registration tool based on mutual information. Starting from this registration, a nonrigid registration was performed. The nonrigid registration also uses mutual information as similarity measure; the deformation field is modeled by tensor-product B-splines [4]. The settings were chosen to allow only coarse or rather global nonrigid deformations, while keeping the local structure unchanged.
During the whole image analysis pipeline, images were downsampled 4 times (to 250 x 250 x 504 voxels). Finally, the obtained transformation was applied to the full-size images.

Results

Figure 1 shows a surface rendering of the reference bone (day 0, red) and the rigidly (green) and nonrigidly (blue) bone at day 28, after registration. It allows visual assessment of the difference between rigid and nonrigid registration. The green and red surface show a relatively good alignment near the joint, while there is a clear mismatch in the shaft of the femur. The red and blue images, on the other hand, globally show the typical patch-like pattern of accurately registered surfaces.

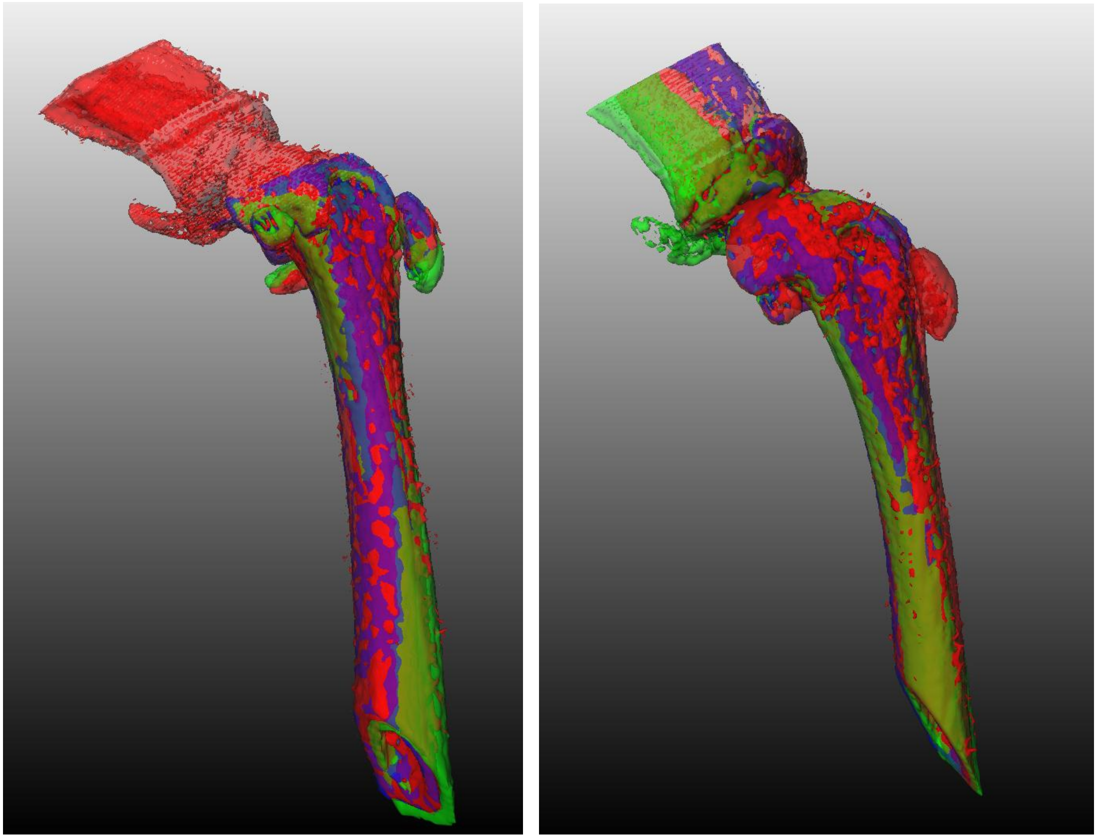
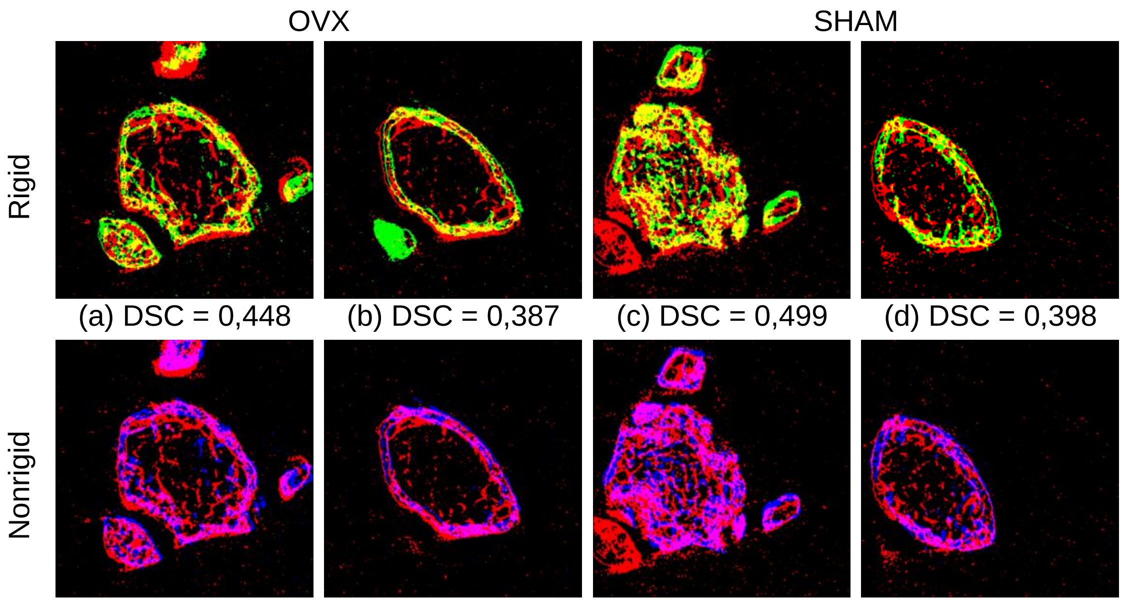


Figure 1: Surface rendering of rigid (green) and nonrigid (blue) registration results of day 24 to day 0 (red) for the OVX (left) and SHAM (right) mouse.



(a) DSC = 0,448 (b) DSC = 0,387 (c) DSC = 0,499 (d) DSC = 0,398

(e) DSC = 0,509 (f) DSC = 0,465 (g) DSC = 0,542 (h) DSC = 0,418

Figure 2: Axial slices of rigid (top row) and nonrigid (bottom row) registration results for the OVX (left) and SHAM (right) mouse. Images show the bone at day 0 (red) and at day 24 (green, blue) after registration. Overlapping voxels are shown in respectively yellow and magenta. Nonrigid registration slightly improves registration results, especially in the cortical bone. DSC = Dice Similarity Coefficient.

Figure 2 shows two slices of the registered datasets, one near the metaphyse and one in the cortex. Each image shows an overlay of the registered dataset (green for rigid, blue for nonrigid) over the day 0 dataset (red). Overlapping voxels are shown in respectively yellow and magenta. In each case, some small improvements can be seen using nonrigid registration. For each slice we also calculated the Dice Similarity Coefficient (DSC), which is a measure of how well both images overlap. The results are shown in Figure 2. Theoretically, the DSC can ranges from 0 (no overlap) to 1 (perfect overlap). The DSC confirms a small yet consistent improvement using nonrigid registration.

Conclusion

Image registration is a helpful tool for the interpretation and quantification of changes in longitudinal imaging studies. Nonrigid image registration can be useful when the study object changes shape over time.

References:

1. J.H. Waarsing, J.S. Day, J.C. van der Linden, A.G. Ederveen, C. Spanjers, N. De Clerck, A. Sasov, J.A.N. Verhaar, and H. Weinansa, *Detecting and tracking local changes in the tibiae of individual rats: a novel method to analyse longitudinal in vivo micro-CT data*, Bone 34 (2004) 163– 169, doi:10.1016/j.bone.2003.08.012
2. K.K. Nishiyama, G.M. Campbell, R.J. Klinck, and S.K. Boyd, *Reproducibility of bone micro-architecture measurements in rodents by in vivo micro-computed tomography is maximized with three-dimensional image registration*, Bone 46 (2010) 155–161, doi:10.1016/j.bone.2009.09.023
3. F. Maes, A. Collignon, D. Vandermeulen, G. Marchal, and P.Suetens, *Multimodality image registration by maximization of mutual information*, IEEE Trans Med Imaging 1997;16:187– 98, doi:10.1109/42.563664
4. D. Loeckx, *Automated nonrigid intra-patient image registration using B-splines*, PhD Thesis, K.U.Leuven, May 2006, Leuven, Belgium, http://hdl.handle.net/1979/298