pyKNEEr: Reproducible Workflow for Automatic Segmentation and Analysis of Femoral Knee Cartilage

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Introduction

Knee osteoarthritis (OA) is a degenerative disease that leads to chronic disability, causing substantial economic and social impact. Magnetic resonance imaging is one of the main tools to quantify early stage and progression of OA by measuring cartilage morphology and relaxometry. Currently, there is a lack of standardized, open-access, and reproducible software to segment and analyze images of the knee femoral cartilage. Researchers mainly segment images manually or semi-automatically, using various commercial or in-house software. In addition, researchers usually perform post-segmentation analysis using commercial software (e.g. Excel, Matlab) and do not publish raw data, compromising results reproducibility.

To promote open-science for quantitative musculoskeletal imaging, we have developed pyKNEEr, a fully-automatic workflow to preprocess, segment, and analyze femoral cartilage of the knee, using novel tools for open-source and reproducible science.

Methods

The workflow of pyKNEEr consists of three stages: image preprocessing, segmentation, and analysis. In preprocessing, images are geometrically aligned to a common cartesian system, and intensities are homogenized and enhanced. Segmentation is implemented using an atlas-based algorithm. It can be performed for a new subject image, or for the same subject in longitudinal or multimodal experiments. Currently, quantitative analysis of the images includes calculation of cartilage thickness using a near-neighbor algorithm and of cartilage volume. pyKNEEr is written in python, using SimpleITK to process images and Elastix [1] for the atlas-based segmentation. For each stage of pyKNEEr, there are one or more Jupyter Notebooks (http://jupyter.org/), an interactive web application that allows reproducible workflows and can be used as a user interface. pyKNEEr is hosted on Github (https://github.com/sbonaretti/pyKNEEr). The documentation was created using Sphinx (http://www.sphinx-doc.org/en/master/).

We validated our workflow on a dataset of 19 images from the Osteoarthritis Initiative (OAI). We assessed segmentation quality using the DICE coefficient, and we compared cartilage thickness and volume obtained with pyKNEEr vs. ground truth using Pearson's coefficient. Jupyter notebooks with results are on Github: https://github.com/sbonaretti/2019_QMSKI

Results

Overlap between pyKNEEr's and ground truth segmentation resulted in an average DICE coefficient of 0.86. Person's coefficients were 0.96 for cartilage thickness and 0.98 for cartilage volume. All results are in the same range as the most recent findings in the literature [2].

Conclusion

We have introduced pyKNEEr, the first open-source, reproducible, and fully automatic workflow for segmentation and analysis of femoral knee cartilage.

References

[1] S. Klein et al. *IEEE Trans. Med. Imaging*, 29, 1, 196–205, 2010.
[2] B. Norman et al. *Radiology*, 288, 1, 177–185, 2018.

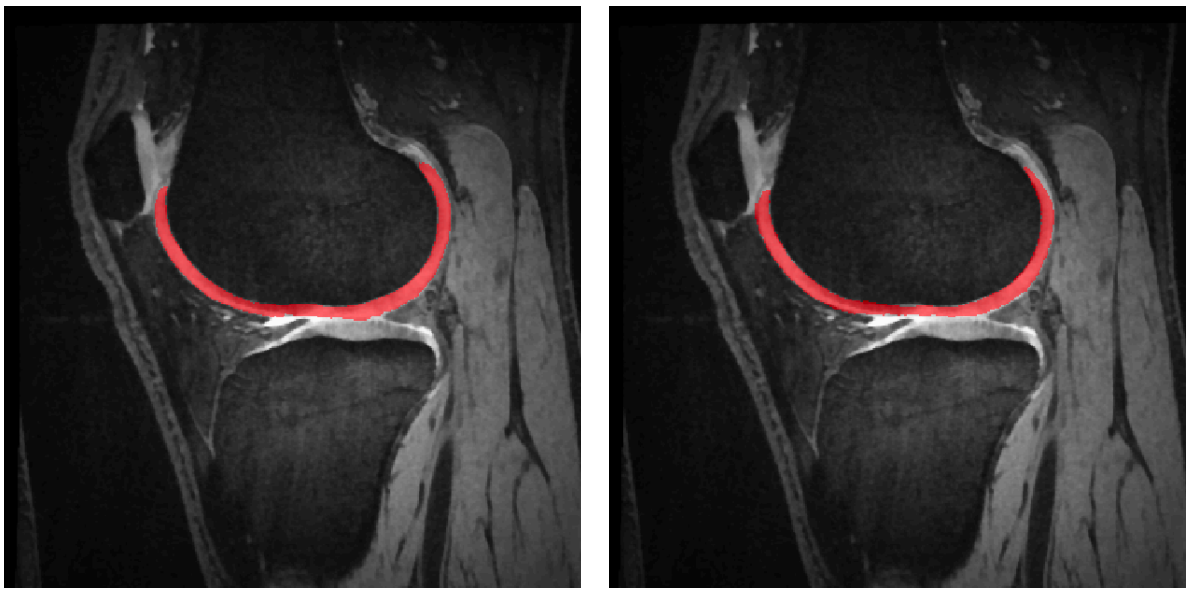

Figure 1: Segmentation of knee femoral cartilage. Left: Ground truth segmentation. Right: Segmentation with pyKNEEr