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Automatic segmentation for volume quantification of quadriceps muscle head: a longitudinal study in athletes enrolled in extreme mountain ultra-marathon

Benjamin Gilles¹, Charles de Bourguignon³, Pierre Croisille^{2,3}, Grégoire Millet⁴, Olivier Beuf³, Magalie Viallon^{2,3}

¹LIRMM; CNRS (UMR 5506) Université de Montpellier, France ² Department of Radiology, Centre Hospitalier Universitaire de Saint-Etienne, Université Jean-Monnet, France, ³CREATIS; CNRS (UMR 5220); INSERM (U1044); INSA Lyon; Université de Lyon, France, ³Department of Radiology, Centre Hospitalier Universitaire de Saint-Etienne, Université Jean-Monnet, France. ⁴Institute of Sport Sciences, University of Lausanne, Switzerland.

Purpose: Acute loss of skeletal muscle mass is a common feature of several pathologies such as stroke, cancer, chronic obstructive pulmonary disease. Whatever the pathology leading to muscle loss, it is associated with worse outcome and hindered quality of life. Whatever the pathology inducing muscle wasting, worse outcome is leading to prolonged hospitalization, prolonged weakness and less efficient rehabilitation. Having a none invasive method to accurately quantify muscle mass is of crucial interest to follow procedure that could prevent muscle wasting and restore physical capacity, mobility and optimize motor recovery. The aim of the current study is to propose an automatic segmentation technique to quantify muscle mass.

Materials and methods: The automatic segmentation of 3D quadriceps volumes was performed using a deformable registration technique ^{1,2} applied to 3D isotropic in-phase (IN), out-phase (OUT), and calculated fat (F) and water (W) images obtained using a double-echo gradient echo Dixon coronal acquisition (Fig1). An initial model was defined by manually segmenting all quadriceps head of interest (vastus medialis, vastus lateralis, vastus intermedius and rectus femoris) and bones (femur, patella and pelvis) from one subject. After conversion to a 3D triangle mesh, this model was considered as a reference template for the registration process. This template was iteratively deformed to match contours in target images from other subjects enrolled in the study. The method was tested in a longitudinal study in athletes enrolled for the most extreme mountain ultra-marathon (The Tor des Géants, Courmayeur, Italy: +24000 positive elevation, 330km). 51 athletes were scans at departure, 27 finishers at the arrival and 2 days after recovery, leading to 105 datasets that were segmented in total. The deformation process was driven by external forces to maximize the correlation between reference and target images around the surface¹, and internal forces to maintain smooth surfaces². The contribution of external forces was iteratively increased to perform a robust coarse-to-fine alignment. 3D volumes were then computed using the final meshes obtained for each quadriceps head. For computing image correlation during registration, all four contrast water, fat, IN-phase and OUT-phase images were compared, including the fusion of all contrast channels/images. The accuracy of the automatic segmentation was assessed based on seven manually segmented datasets (~500-640 axial slices segmented for each of the 7 subjects). The dice similarity coefficient^{2,4} measuring the overlap of segmentations was used: $DSC = \frac{2a}{2a+b+c}$, where a is the number of voxels shared by the expert manual segmentations and the automatic segmentation, b and c are the number of voxels unique to the two segmentations, respectively.

Results: Computation time for the automatic segmentation, including the two sides, was approximately 3 minutes (when using all contrast channels) and 1 minute (when using one contrast). The mean Dice coefficient between automatic estimation of head boundaries using a) In-phase, b) Out-phase, c) Fat, d) water and e) the fused image obtained using all contrast channels, and the manual reference are given in Table 1 for all individual muscle heads, and for all muscles fused together (row 'all'). The mean volumes for Rectus Femoris (RF), Vastus Intermedius (VI), Vastus Lateralis (VL) and Vastus medialis (VM) were measured for all 3 times points of the race. The mean total volume of the quadriceps shows a slight 6,6% increase at the end of the race compared to baseline before the race, that still persist 3 days after recovery (7.5% increase vs baseline).

Discussion & conclusion: For all quadriceps head of interest, the best automatic segmentation accuracy was obtained when using the calculated Water image (DSC=0,946) before the combined channel (DSC=0,938). The mean volume increase in total induced by the race is in the same order as the inter-observer manual segmentation differences (~7,1%), or manual to automatic differences (4,8%). Since large differences were also observed between subjects, these results should be analyzed at the individual level, to identify if the quadriceps volume increase relates to the higher inflammation level observed in the legs of most athletes after extreme eccentric and prolonged solicitation. Given the fast calculation time and the accuracy obtained in this longitudinal study, the technique seems to be mature enough to follow longitudinal variations in normal subjects. It now deserves to be deployed in clinical trials aiming at quantifying the muscle mass to see if similar performances could be obtained in patients with more severe muscle mass changes.

Reference: 1. B. Gilles, N. Magnenat-Thalmann / Medical Image Analysis 14 (2010) 291–302 2. Benjamin Gilles and Dinesh K. Pai, MICCAI 2008). 3. Mazaheri Y et al. Semi-automatic deformable registration of prostate MR images to pathological slices. J Magn Reson Imaging 2010;32: 1149–1157. 4. Zijdenbos AP, et al. Morphometric analysis of white matter lesions in MR images: method and validation. IEEE Trans Med Imaging 1994;13:716–724.

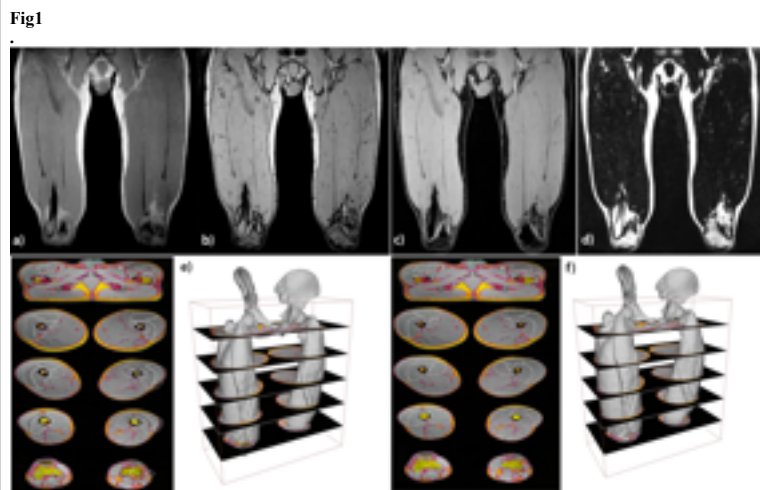
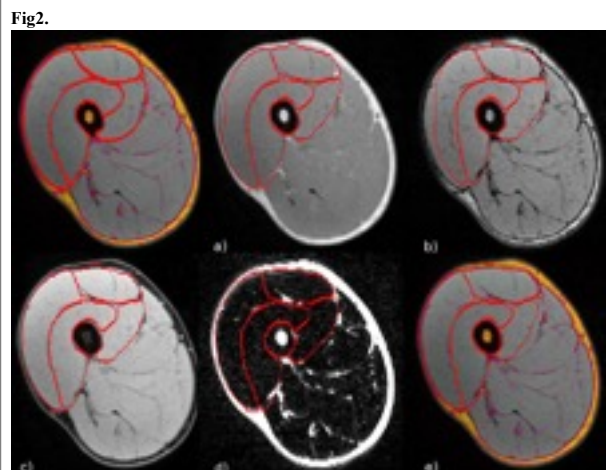


Figure 1 (left): Top: 3D isotropic gradient echo coronal images, showing the different chiefs of interest within the quadriceps with different contrasts: a) in-phase image b) out-phase image c) water image d) fat image. Bottom: Initial (e) and final (f) segmentation results. White overlay fused with the multi-channels images and 3D visualization prior (e) and after (f) registration of the template model.

Figure 2 (right): Manual reference segmentation of the quadriceps muscle. Automatic estimation of head boundaries using a) In-phase, b) Out-phase, c) Water, d) Fat and e) the fused image obtained using all contrast channels. The best results were obtained when using the Water calculated images.



Mean DSC	DSC F	DSC W	DSC In	DSC Out	DSC All
All	0,808	0,946	0,932	0,925	0,938
Rectus_Femoris	0,785	0,881	0,864	0,860	0,871
Vastus_Intermedius	0,650	0,890	0,882	0,872	0,885
Vastus_Lateralis	0,756	0,916	0,893	0,887	0,912
Vastus_Medialis	0,687	0,921	0,900	0,888	0,906