Automatic and Quantitative Assessment of Total and Regional Muscle Tissue Volume using Multi-Atlas Segmentation

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Target Audience: Researches that are interested in assessment of total and regional skeletal muscle tissue volumes.

Purpose: The human muscular system provides stability and locomotive functions of the human body. Age related loss of muscle tissue, Sarcopenia, may lead to physical impairment and is a growing problem related to the ageing population. Detailed information of the human muscular system is needed for further understanding the onset, prevalence and progress of Sarcopenia (1), as well as for other muscular dystrophies. Water-fat separated magnetic resonance images provides high contrast 3D images that enables detailed quantification of total and regional muscle volumes as well as fat infiltration within the muscles.

The purpose of this study was to develop and demonstrate a rapid whole body MR method for automatic quantification of total and regional skeletal muscle volumes.

Methods: The method is based on a multi-atlas segmentation of intensity corrected water–fat separated image volumes. Quantitative intensity corrected water-fat separated volumes were acquired using the methods described in (2-5). Manually segmented muscle groups and the corresponding water-fat volumes were used as atlases. The atlases were non-rigidly registered onto a target. The target's muscle groups were then classified using a voting scheme based on the registered atlases). First, the mask volume was calculated by summing all voxels within the classified label and multiply it with the voxel resolution. Second, voxel with a fat content larger than 50 % was removed so that the resulting segmentation contained only muscle tissue. For the validation, 10 healthy volunteers (6 females, 4 males) with an age range between 22 and 30 years (mean 24.9, std: 2.4 years) were scanned with a ten minute whole body scan on a Philips Achieva 1.5 T (Philips Medical Systems, Best, The Netherlands). A 3D gradient echo sequence with out-of-phase and in-phase echo times of 2.3 ms and 4.6 ms respectively was used. The repetition time was 6.58 ms and the flip angle was 10 ° with a resolution of (3.5*3.5*3.5) mm^3. The method was validated with a leave-one-out approach, using atlases from the 10 subjects as ground truth.

Muscle Volume	CV (mean ± SD)	TPVF	ICC
LeftLowerLeg	2.65 ± 1.96	0.93	0.92
RightLowerLeg	2.01 ± 1.83	0.93	0.95
LeftUpperLegBack	1.74 ± 0.75	0.93	0.99
RightUpperLegBack	1.17 ± 1.08	0.93	0.99
LeftUpperLegFront	1.78 ± 1.49	0.93	0.99
RightUpperLegFront	1.46 ± 0.94	0.93	0.99
Left Abdomen	2.74 ± 1.06	0.80	0.98
Right Abdomen	3.32 ± 2.10	0.82	0.97
Left Arm	7.06 ± 4.14	0.88	0.91
Right Arm	5.44 ± 4.96	0.86	0.94
Whole Body	1.51 ± 1.19	0.91	0.99

Table 1: The coefficient of variation (CV) is presented with mean and standard deviation (SD) for all muscle groups within the atlas. The true positive volume fraction (TPVF) and the intra-class correlation (ICC) are also presented.

Conclusion: The method accurately and precisely quantified the whole body skeletal muscle volume and the volume of separate muscle groups. The method enables cost-efficient large-scale studies, investigating conditions such as sarcopenia and muscular dystrophies.

References: 1. Cruz-Jentoft AJ et. al. European Working Group on Sarcopenia in Older P. Sarcopenia: European consensus on definition and diagnosis: Report of the European Working Group on Sarcopenia in Older People. Age and ageing 2010;39(4):412-423. 2. Dahlqvist Leinhard O et. al. Quantitative Abdominal Fat Estimation using MRI. Proceedings - International Conference on Pattern Recognition (ICPR) 2008;art.no. 4761764. 3. Romu T et. al. MANA - Multi scale adaptive normalized averaging. Proceedings - International Symposium on Biomedical Imaging (ISBI) 2011;art.no. 5872424:361-364. 4. Rydell J et. al. Three dimensional phase sensitive reconstruction for water/fat separation in MR imaging using inverse gradient. International Society for Magnetic Resonance in Medicine (ISMRM). Toronto, Canada 2008. 5. Rydell J et al. Phase sensitive reconstruction for water/fat separation in MR imaging using inverse gradient. International Conference on Medical Image Computing and Computer-Assisted Intervention (MICCAI). Brisbane, Australia 2007.

Results: Visual inspection of the automatic segmentation on the regional muscle groups shows high accuracy, seen in Fig. 1. An excellent intra-class correlation (> 0.9) was achieved for all muscle groups and a low coefficient of variation was achieved, especially on the lower body and the total muscles, presented in Table 1. The true positive volume fraction is also presented in Table 1 and illustrated as yellow color in Fig. 2. A slightly higher variation was shown in the upper part of the body. In the abdominal area, thin muscles near other water-rich organs yields a slightly higher variability. Limitations in the scanner's FOV results in a non-optimal and non-consistent placement of the arms.

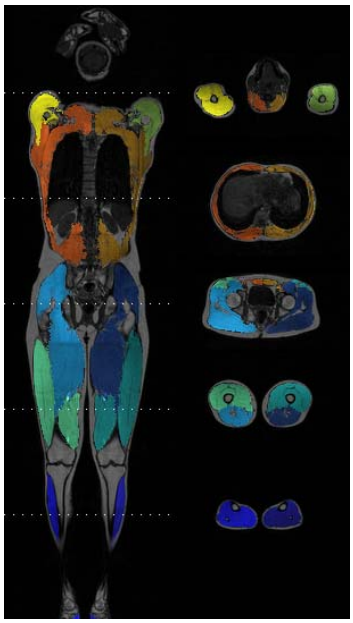

Fig. 2: The resulting segmentation with the automatically labeled muscle groups shown in different colors.

Fig. 2: Showing the result of the whole body muscle tissue segmentation compared to the ground truth manual segmentation. Yellow overlay indicates true positive voxels, red overlay indicates false positive voxels, and green overlay indicates false negative voxels. True negative voxels are shown in gray.