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

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Introduction: To fully understand and diagnose degenerative muscle conditions such as sarcopenia, or muscle loss due to ageing, it is important to determine muscle strength in combination with accurate and precise measurements of the muscle's volume and composition[1]. Water-fat separated magnetic resonance images provide a high contrast 3D image volume, which enables detailed quantification of total and regional muscle volumes, as well as muscular fat infiltration. However, manual definition of muscles is time consuming and does not guarantee low variability between measurements, which is why automatic computer-driven classification of muscle volume is of interest. The purpose of this work was to develop and demonstrate a rapid whole body MRI method for automatic quantification of total and regional lean skeletal muscle volume.

Materials and Methods: Water-fat images were first acquired with two-point Dixon imaging with phase-sensitive reconstruction[2-4]. The images were then intensity inhomogeneity-corrected to acquire quantitative fat information[3,5]. Multiple atlases, consisting of 10 manually defined major muscle groups, were applied onto the acquired image volume, i.e. the target, using non-rigid registration. The groups were: lower leg, posterior and anterior thigh, abdomen, arm on left and right side, illustrated in different colors in Fig.1. Muscle tissue classification was determined using a voting scheme based on the multiple atlas registrations. The muscle tissue was computed by summating the resulting muscle mask for each muscle group after removing pure adipose tissue, using the quantitative fat information.

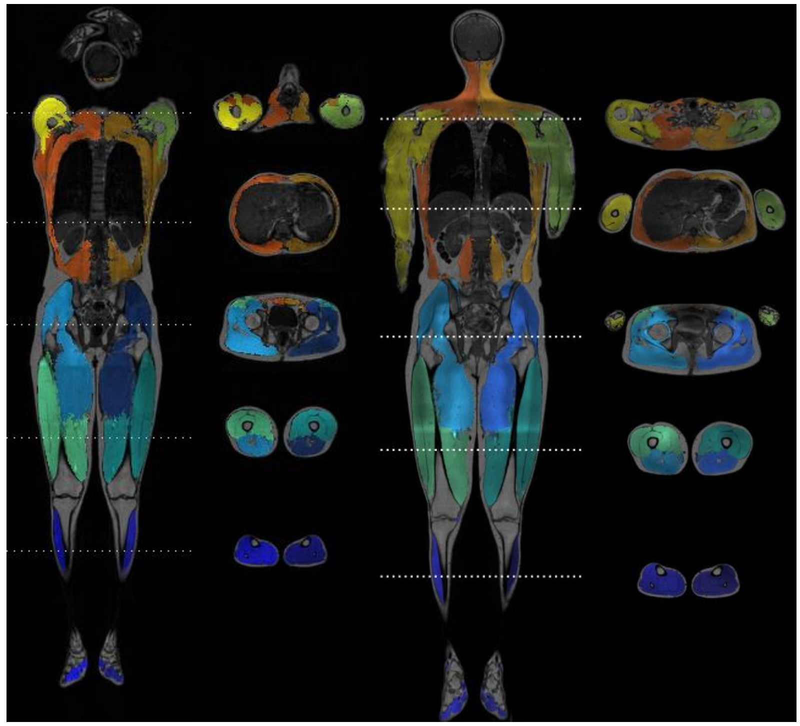

***Fig. 1**: The resulting segmentation with the automatically labeled muscle groups, shown in different colors at 1.5 T (left) and 3.0 T (right).*

Ten healthy volunteers (six female and four male) were included for the creation of atlases, calculation of optimal threshold values at 1.5 T and 3.0 T, and for initial method evaluation using a leave-one-out cross-validation approach. They were scanned with a 1.5 T Philips Achieva MR-scanner and a 3.0 T Philips Ingenia MR-scanner (Philips Health Care, Best, the Netherlands). The time between the two different scans was less than 30 minutes. The ages ranged from 21 to 29 years and the mean age was 24.9 ± 2.4 (standard deviation, SD). The BMI ranged from 20.1 to 32.3 kg/m^2 and the mean BMI was 23.6 ± 3.8 (SD). An additional 11 volunteers (four males, seven females) were scanned in the 3.0 T scanner and were after manual segmentation included as validation data. The ages ranged from 33 to 54 years and the mean age was 43.6 ± 6.8 (SD). The BMI ranged from 19.7 to 32.3 and the mean BMI was 25.8 ± 3.6 (SD). A 3D gradient echo sequence was used with out-of-phase echo times of 2.3 ms (1.5 T) and 1.15 ms (3.0 T). The in-phase echo times were 4.6 ms (1.5 T) and 2.3 ms (3.0 T). The repetition times were 6.58 ms (1.5 T) and 3.78 ms (3.0 T). The flip angles were 13º (1.5 T) and 10º (3.0 T) with a resolution of 3.5*3.5*3.5 mm^3 (1.5 T) and 1.75*1.75*1.75 mm^3 (3.0 T). Delta volumes and the intraclass correlation (ICC) comparing automated to manual segmentations were calculated for each muscle group.

Table 1: *Delta Volumes (Means, SD) and Intraclass Correlation (ICC) between the Manual and the Automatic Muscle Volumes for the 1.5 T, 3.0 T and the Additional 3.0 T Validation (Val) Data.*

	Delta Volume (Standard Deviation)			**Intra Class Correlation**		
Muscle Group	*1.5 T*	*3.0 T*	*Val*	*1.5 T*	*3.0 T*	*Val*
Left lower leg	0.03 (0.08)	0.04 (0.08)	0.05 (0.04)	0.92	0.91	0.99
Right lower leg	0.02 (0.06)	0.02 (0.08)	0.07 (0.06)	0.95	0.90	0.97
Left posterior thigh	-0.03 (0.08)	-0.03 (0.08)	0.19 (0.06)	0.99	0.99	0.98
Right posterior thigh	-0.03 (0.06)	-0.03 (0.12)	0.10 (0.09)	0.99	0.98	0.99
Left anterior thigh	0.01 (0.07)	0.03 (0.08)	-0.06 (0.06)	0.99	0.99	0.99
Right anterior thigh	0.01 (0.05)	0.01 (0.06)	0.02 (0.04)	0.99	0.99	1.00
Left abdomen	-0.08 (0.15)	-0.03 (0.42)	0.04 (0.27)	0.98	0.89	0.97
Right abdomen	-0.04 (0.22)	-0.05 (0.38)	0.01 (0.24)	0.97	0.89	0.97
Left arm	0.15 (0.14)	0.03 (0.13)	0.40 (0.43)	0.91	0.98	0.75
Right arm	0.13 (0.12)	0.08 (0.19)	0.38 (0.29)	0.94	0.95	0.86
Whole body	-0.10 (0.70)	-0.17 (1.37)	0.76 (0.83)	0.99	0.97	0.99

Results: The mean muscle volumes were similar regardless of operator (manual or automatic) and of scanner modality/resolution for all muscle groups. The delta volumes and ICC for the initial 1.5 T data, 3.0 T data and the additional 3.0 T validation data are presented in Table 1. A typical result of the multi-atlas segmentation is shown in Fig. 1 for both 1.5 T (left) and 3.0 T (right).

Discussion and Conclusion: The method accurately quantified the whole-body lean skeletal muscle volume and the volume of separate muscle groups, independently of field strength and image resolution. There was higher variability in the upper part of the body than in the lower part, due to inconsistent placement of arms and FOV restraints. Age and BMI differences do not seem to affect the result of the method's performance. The method showed high accuracy, even though lean young subjects were used as atlases and the validation data had slightly larger and much older subjects. This is also in agreement with a recent study investigating the repeatability of this method[6]. The present work shows that the method also provides accurate and reproducible muscle volume estimates. Future work includes optimization of the method for quantifying intra-muscular adipose tissue, a potential biomarker for muscle pathology.

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]Romu T et. al. MANA - Multi scale adaptive normalized averaging. Proceedings - International Symposium on Biomedical Imaging (ISBI) 2011;art.no. 5872424:361-364. [3]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. [4]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. [5]Dahlqvist Leinhard O et. al. Quantitative Abdominal Fat Estimation using MRI. Proceedings - International Conference on Pattern Recognition (ICPR) 2008;art.no. 4761764. [6]Thomas MS, et al. Test-retest reliability of automated whole body and compartmental muscle volume measurements on a wide bore 3T MR system. Eur Radiol 2014.*