Automated multimodal segmentation of paraspinal muscles based on chemical shift encoding-based water/fat-separated images

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Introduction

Chronic lower back pain (LBP) is the most prevalent musculoskeletal disorder among adults [1,2]. Research suggests paraspinal muscle atrophy and fatty infiltration as accurate indicators of LBP, which can be determined through extraction of proton density fat fraction (PDFF) maps from chemical shift encoding-based water-fat MRI [3,4]. However, the use of water-fat MRI in clinical routines is limited due to the lack of an accurate segmentation procedure of muscle compartments. In this work, we utilize water-fat MRI and deep learning (DL) to automate paraspinal muscle segmentation and explore how to use multimodal data more effectively in DL.

Subjects / Methods

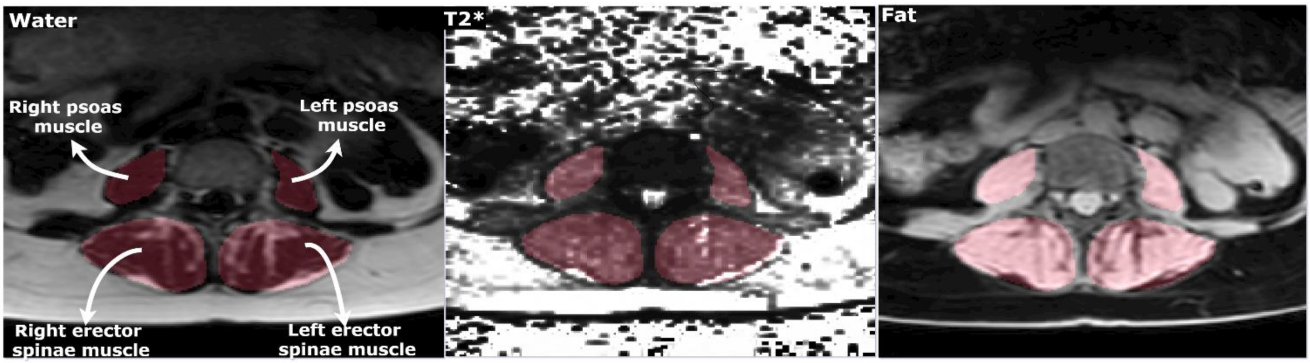
We utilize 54 MRI datasets of healthy volunteers acquired from a 3T Philips Ingenia system containing axial water, fat and T2* [5]. Manual segmentations of right/left erector spinae and psoas muscles were obtained from axial PDFF maps by a board-certified radiologist. Use of convolutional neural networks for paraspinal muscle segmentation is challenging due to unclear boundaries, variable muscle shape and complex background [6], which can be addressed by contrast variation and better data representation in water-fat MR. However, effective integration and extraction of features that fully leverage information in multimodal data is still unexplored. We employ a 3D U-Net on water-fat and T2* images (Fig.1a) by fusing them into three channels at the input (early fusion) and compare it to the late fusion approach of three encoder paths fused at the bottleneck of the U-Net (Fig.1b) to better handle multimodal data complexity.

Discussion

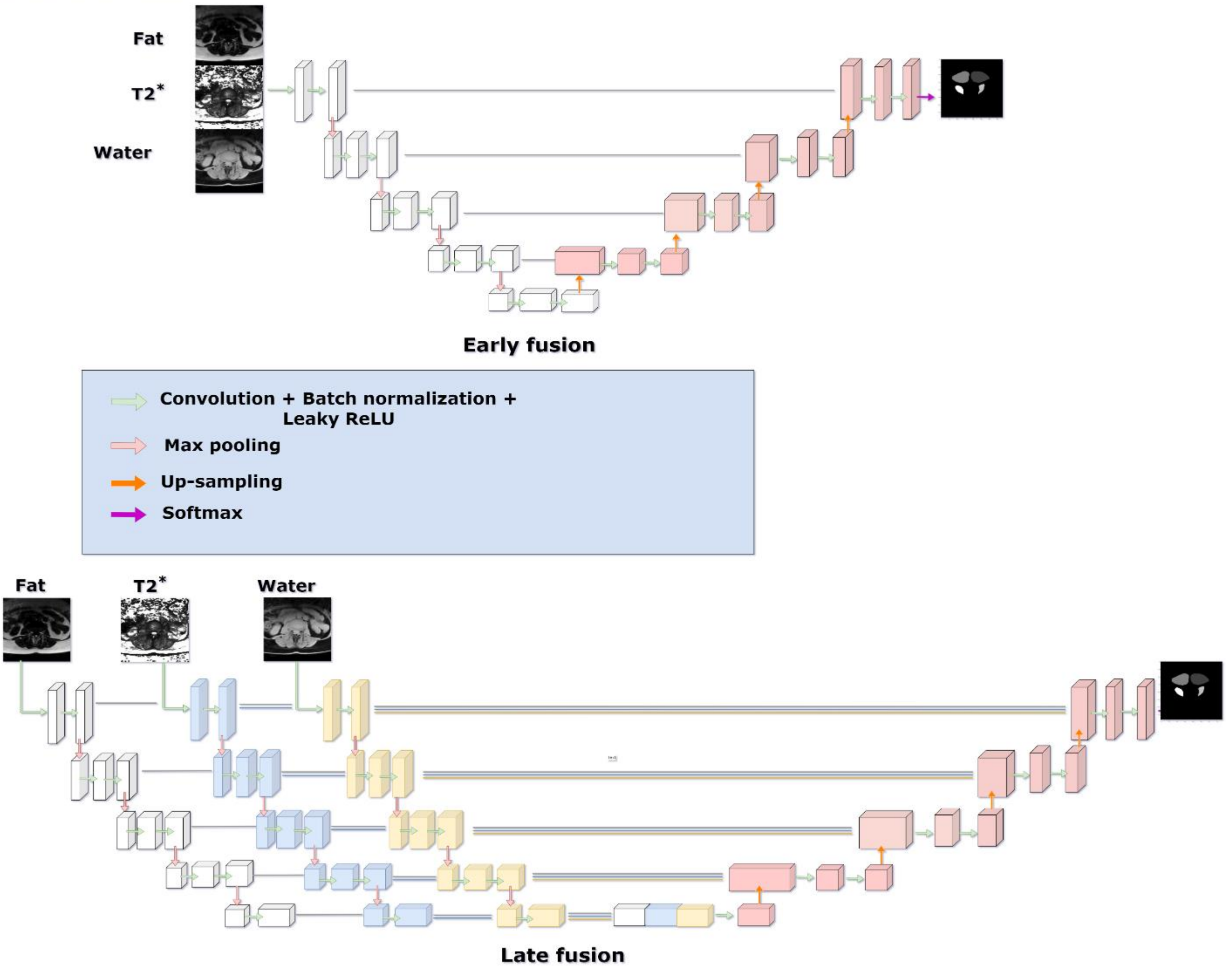
Obtained results (Fig.1c) demonstrate that both multimodal data and late fusion improve paraspinal muscle segmentation, despite the mentioned challenges and data limitations. Compared to the early fusion approach, late fusion solves the problem of significant overestimation of the erector spinae muscles and improves the generalization to poor contrast. To conclude, this study suggests that DL-based segmentation significantly benefits from multimodal data, where feature extraction from different modalities at separate stages outperforms early data merging.

References

[1] Al-Kafri et al. IEEE Access, 43487–43501, 2019
[2] Panagopoulos et al. AJNR 38(9), 1826-1832, 2017
[3] Beneck et al. Archives-PMR, 93(2), 300-306, 2012
[4] Baum et al. EJR, 85(8), 1512-1518, 2016
[5] Burian et al. BMC MD, 20(1), 152, 2019
[6] Li et al. Sensors, 19(12), 2650, 2019
[7] Baum et al. ER Exp, 2(1), 1-5, 2018



(a) Representative slices from one of the multimodal MRI volumes in the training set, contaning water, T2* and fat images, with manually segmented target muscle compartments. All data is normalized to zero mean and unit standard deviation.



(b) Early and late fusion architectures used in the paper. Both networks are trained under the same settings, using the sum of cross-entropy and dice loss and Adam optimizer with the starting learning rate of 10^{-4} and weight decay of 10^{-4}. Both networks converge after 180 epochs.

Method	Erector Spinae (L)	Erector Spinae (R)	PSOAS (L)	PSOAS (R)
Early fusion 3D U-Net	0.859	0.867	0.835	0.853
Late fusion multi-pathway 3D U-net	0.869	0.872	0.851	0.862
Literature [7]	0.90	0.89	0.77	0.83

(c) Segmentation performance of early and late fusion 3D U-Net-based networks on the task of paraspinal muscle segmentation on water-fat MR images with comparison to the results reported in the literature [8]. All reported scores are mean Dice coefficients per each test case. Both networks are trained on 40 images and tested on the remaining 14 multimodal MR images.

Figure 1: Details and results of the proposed work.