COMPUTER METHODS AND PROGRAMS IN BIOMEDICINE 120 (2015) 37–48

journal homepage: www.intl.elsevierhealth.com/journals/cmpb

Computer-based assessment for facioscapulohumeral dystrophy diagnosis

O. Chambers[a,*], J. Milenković[b,d], A. Pražnikar[c], J.F. Tasič[b]

[a] Institute "Jožef Stefan", Jamova cesta 39, 1000 Ljubljana, Slovenia
[b] University of Ljubljana, Faculty of Electrical Engineering, Tržaška cesta 25, 1000 Ljubljana, Slovenia
[c] University Medical Centre of Ljubljana, Department of Neurology, Zaloška cesta 2, 1000 Ljubljana, Slovenia
[d] Faculty of Medicine, Vražov trg 2, 1000 Ljubljana,Slovenia

ARTICLE INFO

Article history:
Received 25 November 2014
Received in revised form
27 February 2015
Accepted 23 March 2015

Keywords:
MRI
Hyperintensity quantification
Muscle dystrophy
Muscle-region segmentation
FSHD

ABSTRACT

The paper presents a computer-based assessment for facioscapulohumeral dystrophy (FSHD) diagnosis through characterisation of the fat and oedema percentages in the muscle region. A novel multi-slice method for the muscle-region segmentation in the T1-weighted magnetic resonance images is proposed using principles of the live-wire technique to find the path representing the muscle-region border. For this purpose, an exponential cost function is used that incorporates the edge information obtained after applying the edge-enhancement algorithm formerly designed for the fingerprint enhancement. The difference between the automatic segmentation and manual segmentation performed by a medical specialists is characterised using the Zijdenbos similarity index, indicating a high accuracy of the proposed method. Finally, the fat and oedema are quantified from the muscle region in the T1-weighted and T2-STIR magnetic resonance images, respectively, using the fuzzy c-mean clustering approach for 10 FSHD patients.

1. Introduction

Facioscapulohumeral dystrophy (FSHD) is the third most common muscular dystrophy after Duchenne's and myotonic dystrophy [1]. FSHD is characterised by progressive degenerative changes in the muscle fibres resulting in accumulation of the IntraMuscular Fat (IMF) [2,3]. IMF can be defined as a sum of the infiltrated fat within the muscle region and intermuscular fat between individual muscle groups [4]. Research studies indicated a correlation between the muscle force and level of IMF in the muscle region of the FSHD patients [5,6], which could provide an important prediction for the disease progression [7]. The T1-weighted magnetic resonance imaging (MRI) serves as a non-invasive biomarker of the IMF distribution in the lower limb enabling therapy-treatment estimation [8].

Interpretation of the MRI images to determine whether the FSHD pathology is present or not is relatively easy, however, it is much more difficult to quantify the muscle changes both in terms of the affected muscle-volume percentage and disease progression. Recently, the increased water mass, or oedema, has been demonstrated as a crucial intermediate state of the change between the healthy muscle and fatty replacement [9,10]. The oedema areas characterised by an increased signal in the T2-weighted short-tau inversion recovery (T2-STIR) images in muscles not yet replaced by a fat tissue may show a normal signal in the T1-weighted images [11]. Therefore, this

* *Corresponding author*. Tel.: +386 1 477 39 00; fax: +386 1 251 93 85.
E-mail address: olga.chambers@ijs.si (O. Chambers).

http://dx.doi.org/10.1016/j.cmpb.2015.03.006
0169-2607/

complementary source of information is necessary to estimate the FSHD progression and to make therapeutic decisions.

Manual assessment of the FSHD progression in the MRI images is a relatively complex and subjective task for large datasets. Therefore, automatic and semi-automatic methods of segmentation and quantification for diagnostic assessment are preferable in clinical evaluation. In the literature, the muscle-region segmentation is commonly performed on the fat-unaffected muscle structures, where a good contrast between the subcutaneous adipose tissue (SAT) and muscle tissues is observed. In those cases, the segmentation is usually performed by using a simple histogram analysis and thresholding operations [12]. More advanced techniques for the muscle-region segmentation incorporate both the spatial and intensity information of pixels. The fuzzy c-mean (FCM) clustering [13,14] and level-set approach [15–18] are the most commonly used techniques [19,17]. However, the presence of IMF in the muscle region of patients affected by FSHD makes the segmentation more difficult, because of the IMF and SAT gray-level intensity similarity. Moreover, the spatial resolution limitations blur the border between SAT and IMF making it almost invisible. Wald et al. [14] proposed a morphological opening with a circular structure element to break any connection between SAT and IMF after using the FCM clustering. However, this may lead to a loss of the muscle-region border information. By using the level-set approach, Positano et al. in [17] observe intrusion of the internal SAT border into the intermuscular fat. Moreover, the blood-vessel regions may significantly affect the effectiveness of the level-set approach. A more recent work of Commean et al. in [20] proposes the use of the second derivative of brightness in the fat-saturated MRI images for semi-automatic delineation of the lower-limb anatomical elements, where the user is required to break connections in the binary edge map between individual elements. This method is sensitive to the texture edges and IMF in muscles. The authors reported that more advanced edge-detection techniques may improve results.

In this paper, an edge-enhancement algorithm designed for fingerprint enhancement is used for segmentation showing advantages over the classical edge-detection methods for the lower-limb segmentation. The proposed method uses the basic principles of the live-wire technique introduced by Mortensen and Barrett [21], where the manual interaction is substituted with an automatic seed-point placing. Originally, this technique searches the path with the smallest cost between the manually placed seed points, where the cost is calculated by incorporating the information from the edges obtained by the Laplace zero-cross filtering, gradient magnitude and gradient direction.

The multi-slice muscle-region segmentation is performed in two phases. During the first phase, the muscle region of the lower-limb with the largest cross-section area is segmented and used to perform segmentation in the adjacent slices during the second phase. The obtained results using the proposed method are compared with the results of the FCM clustering and level-set approach with respect to the medical specialists' annotations using two metrics, the root mean square and Zijdenbos similarity index. Finally, the fat and oedema percentages in the muscle region are calculated to characterise the FSHD progression.

2. Materials

2.1. *Magnetic resonance imaging parameters*

Our MRI examination of 10 patients with a genetically confirmed diagnosis of FSHD was performed on a 3.0T Philips scanner using the software version 3.2.1. Imaging was made at the calf level with a 5-mm thickness parameter.

The T1-weighted images were acquired using a Fast Spin-Echo (FSE) sequence with the following parameters: TE/TR = 20/500 ms, ETL = 3 (Echo Train Length), NEX = 1, 784 × 784 acquisition matrix size, FOV = 330 mm.

The T2-STIR images were acquired using an FSE sequence with the following parameters: TE/TR = 30/1400 ms, ETL = 15, NEX = 2, 1152 × 1152 acquisition matrix size, FOV = 330 mm and 5 mm slice thickness.

2.2. *Dataset description*

The T1-weighted and T2-STIR MRI images contain a different but complimentary information necessary for a computer-based diagnostic assessment of FSHD. The T1-weighted MRI images of the lower limbs provide information required for the muscle-region segmentation and fat quantification, while the T2-STIR images provides information required for the oedema quantification [22]. Fig. 1 shows a typical example of the T1-weighted and T2-STIR images of a patient with FSHD.

Anatomically, the muscle region is surrounded by SAT. In the FSHD patients, the muscle region contains also IMF [23]. Each bone, e.g. fibula and tibia, is constructed of a bone marrow (higher signal intensity) and surrounding cortical bone (lower signal intensity). In the T1-weighted MRI images the muscle tissue appears as a medium grayscale intensity level, while SAT surrounding the muscle region and IMF appear with a high grayscale intensity level similar to that of the bone marrow.

The intensity inhomogeneity may be observed in the T1-weighted images as signal-intensity variations. T2-STIR has a higher signal-to-noise ratio, however, it is independent of the magnetic-field inhomogeneity.

3. Methods

The muscle-region segmentation is performed in the T1-weighted MRI images incorporating information from the adjacent slices. After segmentation, quantification is performed to estimate the fat/oedema percentage in patients with FSHD.

3.1. *Muscle-region segmentation*

The proposed segmentation method relies on the anatomy similarity between the adjacent slices. The segmentation is performed in two phases illustrated in Fig. 2. It can be noticed that both phases have a similar flow. The principal difference between them refers to the input parameters for the shortest-path search, where the shortest-path search technique is used to find the path along the SAT internal border.