Automated recognition of the iliac muscle and modeling of muscle fiber direction in torso CT images

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ABSTRACT

The iliac muscle is an important skeletal muscle related to ambulatory function. The muscles related to ambulatory function are the psoas major and iliac muscles, collectively defined as the iliopsoas muscle. We have proposed an automated recognition method of the iliac muscle. Muscle fibers of the iliac muscle have a characteristic running pattern. Therefore, we used 20 cases from a training database to model the movement of the muscle fibers of the iliac muscle. In the recognition process, the existing position of the iliac muscle was estimated by applying the muscle fiber model. To generate an approximation mask by using a muscle fiber model, a candidate region of the iliac muscle was obtained. Finally, the muscle region was identified by using values from the gray value and boundary information. The experiments were performed by using the 20 cases without abnormalities in the skeletal muscle for modeling. The recognition result in five cases obtained a 76.9% average concordance rate. In the visual evaluation, overextraction of other organs was not observed in 85% of the cases. Therefore, the proposed method is considered to be effective in the recognition of the initial region of the iliac muscle. In the future, we will integrate the recognition method of the psoas major muscle in developing an analytical technique for the iliopsoas area. Furthermore, development of a sophisticated muscle function analysis method is necessary.

Keywords: Psoas major muscle, Iliopsoas muscle, Iliac Muscle, Muscle Direction Model, CAD

1. INTRODUCTION

The impairment of iliac muscle function is strongly associated with falls in the elderly. Falls among the elderly are due to functional deterioration of the iliopsoas muscle, which consists of the psoas major and iliac muscles [1]. Furthermore, along with the iliopsoas muscle, skeletal muscle decreases with age. Therefore, quantitative analysis of the iliopsoas muscle function is considered to be useful in the prevention of falls in the elderly.

We have developed a site-specific recognition method of skeletal muscle by using torso computed tomography (CT) without contrast enhancement [2]. In particular, the automated method of recognition of the psoas major muscle, which is closely related to the iliac muscle, has already been established [3]. Therefore, the relationship between the iliopsoas muscle function and walking ability using the iliac muscle should be analyzed.

The iliac muscle is a skeletal muscle that acts on the anteversion of the iliac, which affects the bending of the hip joint and spine. Therefore, quantitative analysis of the iliopsoas muscle is required for automated recognition of the iliac muscle, which is part of the iliopsoas muscle.

In this study, we propose an iliac muscle fiber model with a characteristic running pattern and a method of using the model for recognition of the iliac muscle. By recognition of the iliac muscle, the area, volume, and shape of the muscle in the iliopsoas region can be quantitatively analyzed. Therefore, this model can provide support for fall prevention in the elderly.

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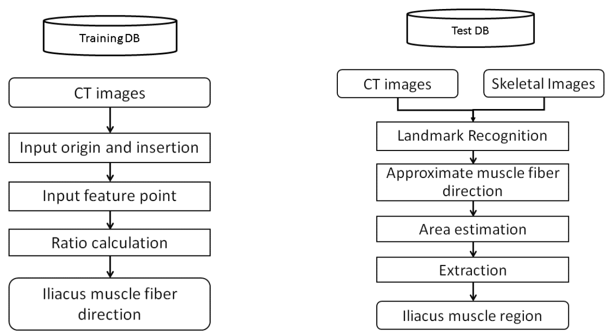
2. METHODS

We describe the methods of modeling the muscle fiber direction of the iliac muscle and recognition of the iliac muscle by using a model derived from torso CT images. Figure 1 shows the flowchart of our proposed method. The input images are torso CT images without contrast enhancement and skeletal images. The skeletal images were generated by classifying the automatically recognized bone region by using the CT values and connectivity on the torso CT images [4].

First, a training database was used to model the curvature and length of the muscle fibers of the iliac muscles. Next, as an anatomical position feature of the iliac muscle, landmarks (LMs) corresponding to the origin and insertion were identified from the test subjects. In the recognition process, the muscle fiber model of the iliac muscle was fitted to the obtained LMs. In the fitting process, the feature values calculated in advance from the training database were used in order to obtain the curves that reflect the individual differences between the test subjects. Next, by using the curves, the shape of the iliac muscle was approximated on the curved surface. Finally, the unextracted regions were precisely extracted by using anatomical position features.



(a) Training, (b) Recognition

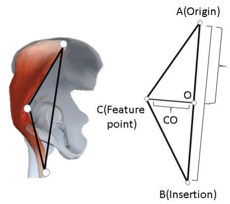
Figure 1. Flowchart of our proposed method

2.1 Modeling of the muscle fiber direction

The model of the muscle fibers for iliac muscle depicts the characteristic running pattern of the muscle fibers of the iliac muscle, as seen in the curve in Figure 2(a). The iliac muscle has a curved shape toward the insertion from the origin [5]. In the modeling of the running of the muscle fibers, we used three anatomical feature points, namely the origin, insertion, and middle points of the iliac muscle. These three points are interpolated to the curve by using a spline function to obtain the running curve of the muscle fibers.

Figure 2 shows the running model of the iliac muscle fibers. Figure 2(a) shows the diagram fitted approximately to the triangle on the iliac muscle that connects the ilium and femur. By fitting the anatomical feature points in this triangle, the unique shape and individual differences between the iliac muscles could be represented. Figure 2(b) shows the schematic diagram of the approximation model. A corresponds to the LM of origin; B, to the LM of insertion; C, to the Feature point of fiber direction; and O, the midpoint of AB. Then, the running of the muscle fibers is expressed by the ratio of the distance as CO/AB. In addition, with the upper and lower body axis positions, the distance ratio could be calculated as AO/AB.

In the training, the ratio was calculated by using 20 training cases. Each point was manually inputted by a physician from the original CT images. The values of CO/AB for the left and right iliac muscles were 0.360 and 0.369, respectively. Similarly, the left and right values of AO/AB were 0.646 and 0.644, respectively. In the recognition described below, the characteristic point C was calculated by using these values and the origin and insertion LMs, which were recognized automatically. Then, spline curve interpolation was applied by using these three points to obtain a traveling curve of the iliac muscle. Figure 3 shows the traveling curve of the iliac muscle fibers and the three LMs detected automatically.



(a) The muscle fiber [5]. (b) The muscle fiber model
Figure 2. Muscle fiber model of the iliac muscle

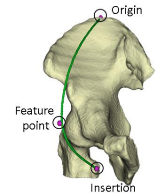


Figure 3. Muscle fiber curve and LMs

2.2 Recognition of the anatomical feature points (LMs)

For the iliac muscle, as for other skeletal muscles, the connecting points on the skeleton were defined as the origin and insertion, which are the anatomical feature points. We defined the (surrogate) points corresponding to the anatomical feature points on the computer as LMs. The same point of the anatomical definition is regarded as the LM of the insertion, whereas one point from the outer lip of the iliac is treated as LM of the origin.

Each LM was recognized by using the skeletal images as input image. First, based on the anatomical definition, the skeleton to be recognized with LMs was selected. Then, the LMs were automatically recognized from the skeleton by using spatial position information. The position features on the sagittal plane were used to identify the LM of insertion. Similarly, the position features on the axial plane were used to identify the LM of origin. On the computer, the anatomical definition of the origin was an outer lip. Automated recognition feasibly and consistently identifies the outer lip of the iliac as a LM.

2.3 Area Estimation

The existing region of the iliac muscle was estimated by using LMs and the iliac muscle model based on surface approximation. The direction of the muscle fiber was obtained by using the estimated point from the model and two LM points connected by a spline curve. However, we did not set the LM of the origin on only one point.

Anatomically, the iliac muscle attaches to the ilium. Therefore, two feature points are used to identify the outer lip of the iliac. These two points are detected on the left and right boundaries of the outer lip of the iliac. By connecting the curve of the muscle fibers, the surface shape of the iliac muscles at the origin side is approximated. This approximated area is defined as the mask image.

2.4 Extraction of iliac muscle region

Extraction of the iliac muscle region was performed by using the mask image obtained previously. Global extraction was performed by using the CT values of the mask area in order to obtain the initial region of the iliac muscle.

In the precise extraction process, the region of the iliac muscles after global extraction was considered as the initial region, to which the region growing method is applied. A stopping condition of the region growing method was set at the area of the growing region by using CT values of the tendon and fat region.

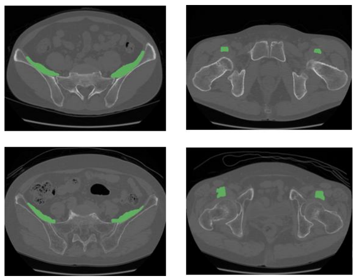
3. EXPERIMENT AND RESULTS

Twenty torso CT images without contrast enhancement and abnormalities in the muscle region were used. The number of pixels and slices were 512 × 512 and 802–1104, respectively. The spatial resolution was 0.625 mm. The image used as the gold standard was obtained under the guidance of a physician. The average concordance rate, which is in this evaluation experiment referred to the Jaccard similarity coefficient values, recall rate, and adaption rate were determined in 5 cases as quantitative evaluation. In addition, visual evaluation was performed in the 20 cases.

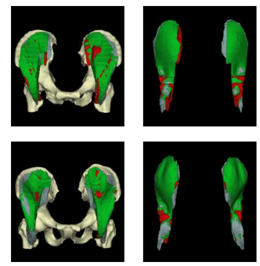
The average concordance rate, recall rate, and adaption rate in the 5 cases were 76.9%, 81.8%, and 93.3%, respectively. Figure 4 shows the result of superimposing an extraction result to the original CT images. The left column shows the images around the origin, and the right column shows the images around the insertion. From the top, images from 20-, 70-year-old patients are shown. The concordance rates were 72.5%, 80.0%, and 84.7%, respectively. Figure 5 shows the three-dimensional representation of the same cases as Figure 4. The green area shows the matching area with the gold standard, the gray area shows the unextracted region, and the red area shows the overextracted region.

A good average concordance rate of 76.9% of the recognition result was obtained. This result is due to the correct modeling of the running pattern of the muscle fibers of the iliac muscle. In particular, the running curve of the muscle fiber was satisfactorily expressed. Thus, a summary of the individual differences could be realized by using a ratio. Therefore, the middle region of the iliac muscle was satisfactorily recognized.

However, in the visual evaluation of 20 cases, false recognition of the large intestine was observed in three patients. These patients had a descending intestine caused by the small difference in density value of the boundary of the iliac muscle and large intestine.



(a) Around the origin (b) Around the insertion
Figure 4. Extraction result with original CT image



(a) Anterior side (b) Dorsal side
Figure 5. Comparison between the recognition results and the criterion standard

4. CONCLUSION

In this study, automated recognition of the iliac muscle and modeling of the muscle fiber direction on torso CT images were achieved. The running pattern of the muscle fibers of the iliac muscles was depicted, and modeling of the characteristic curve that connects the origin, insertion, and central areas of the iliac muscle was achieved. With correct representation of the distance value to the curved portion and the distance value between the origin and end by using the ratio, individual differences could be correctly represented. The validity of the method should be verified in a future work by using more experimental cases. In addition, a recognition method of the psoas major muscle [3] should be integrated in the development of an automated recognition of the iliopsoas muscle.

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