A method for the segmentation of the anterior fascia of the abdominal muscle

Ricardo J. Araújo
ricardo.j.araujo@inesctec.pt
Hélder P. Oliveira
http://www.inescporto.pt/~hpo/

Abstract

The segmentation of the anterior fascia of the abdominal muscle is an important step towards the analysis of abdominal vasculature. It may advance Computer Aided Detection tools that support the activity of physicians who study vessels for breast reconstruction using the Deep Inferior Epigastric Perforator flap. In this paper, we propose a two-fold methodology to detect the anterior fascia in Computerized Tomographic Angiography volumes. First, a slice-wise thresholding is applied and followed by a post-processing phase. Finally, an interpolation framework is used to obtain a final smooth fascia detection. We evaluated our method in 20 different volumes, by calculating the mean Euclidean distance to manual annotations, achieving subvoxel error.

1 Introduction

In the United States, breast cancer is the leading cause of cancer death in women aged 20 to 59 years, being only surpassed by lung cancer in higher ages, a tendency that is observed worldwide [6]. The mastectomy, a surgical procedure where the whole breast is removed, is still frequently performed and has even been increasing in some institutions [3]. Fortunately, the psychological burden of such procedure may be alleviated with the reconstruction of the breast. Among the available options, the Deep Inferior Epigastric Perforator (DIEP) flap has become the state-of-the-art technique for autologous tissue based breast reconstruction [2]. In this study, skin, fat and vessels are moved from the abdominal region to the chest, without weakening the rectus abdominis muscle, also known as abdominal muscle. The harvested vessels are the DIEPs, regularly known as perforators. They have origin in bifurcations of the Deep Inferior Epigastric Arteries (DIEAs) and then perforate the abdominal muscle, heading to the superficial tissues of the abdomen (see Figure 1 for a representation of the local anatomy).

As microsurgery techniques are involved in this type of harvest, medical imaging has been used for preoperative planning. A physician describes the existing perforators, since the viability of the flap is related to the features of the extracted perforator(s) [5]. Characteristics from both the subcutaneous and intramuscular portions of the perforators are taken into account. The anterior fascia of the abdominal muscle separates both of these regions, hence its automatic segmentation facilitates the use of computer based routines to automatically retrieve the required measures. Furthermore, the automatic detection of the fascia would help to determine the origin of each perforator subcutaneous course, which is required to create an accurate map of the dissection locations.

Organs, such as the liver and pancreas, have been segmented using manually labeled atlases and the graph cuts method [7]. However, the abdominal muscle has not been targeted by other authors. In this paper, we describe a semi-automatic method for the segmentation of the anterior fascia of the abdominal muscle, in the region where the perforators arise, based on [1].

2 Abdominal muscle anterior fascia segmentation

The relevant region for DIEP analysis is given by the volume that includes the end of each perforator and the locations where the DIEAs enter the posterior lamella of the abdominal muscle (see Figure 1). A margin was considered to avoid losing segments of tortuous vessels.

In terms of image intensities, the fascia cannot be distinguished from the abdominal muscle. Hence, it is considered to be the boundary between this muscle and the subcutaneous region, characterized by a transition from pixels with low intensity (subcutaneous region) to pixels with higher intensity (muscle), which exists over all the columns of each axial slice of the volume of interest (see Figure 2).

2.1 Preliminary segmentation

To obtain a preliminary segmentation of the anterior fascia, we conducted some processing steps. Let \( B_s \) be the binary image after step \( s \). Figure 3 shows the binary images after step \( s \) with respect to the examples present in Figure 2. The involved steps are described below:

1. Otsu’s thresholding: The Otsu’s method [4] was used to obtain a threshold that distinguishes the muscle from the subcutaneous region. Occasionally, there are structures that also respond to the threshold and appear connected to the anterior region of the muscle, such as perforators and umbilical tissue. The last modules of the pipeline address these unwanted detections.

2. Skin removal: The regions of the original image, where the intensities are equal to zero, are extracted (they include the region outside the body of the patient and cavities filled with air). Among those regions, the area outside the body of the patient is obtained by keeping the largest connected component. Its dilated version is used to remove the skin object present in \( B_s \).

3. Largest connected component: The largest connected component that exists over all the columns of \( B_s \) is selected. If there is none, we iteratively decrease the threshold until such requirement is satisfied.

4. Filling operation: Regions lying below the biggest connected component are filled.

5. Umbilical tissue removal: Some images have umbilical tissue connecting the skin and muscle regions. When that occurs, it is common that \( B_s \) includes an unwanted detection of part of the umbilical tissue (see the bottom row of Fig. 3). To detect slices where this happens, we analyze whether the skin object removed in step 2 is adjacent to \( B_s \). This is true if the logical OR operation between them creates a single object. If this is the case, the horizontal derivatives of the OR image are obtained through the Sobel
operator, which produces high responses at the isthmus that links the skin and $B_3$. From those detections, a rectangular mask is created and used to remove the connection, producing $B_5$. If not, $B_5$ is equal to $B_4$.

6. Preliminary fascia detection: Vertical transitions are obtained for each column of $B_5$. Connected contours, considering 8 neighbors, smaller than $n$ pixels, where $n$ was empirically set to 11, are discarded. We lose the influence of vertical oriented structures which might be still connected to the segmentations, such as vessels.

### 2.2 Final segmentation

To obtain a complete and smooth result, we use a regression framework that takes as input the preliminary fascia segmentation. In sagittal slices, the boundary between the muscle and the subcutaneous region is usually very smooth. For each row of each sagittal slice of our volume of interest, a new fascia point $(P_{row}, P_{col})$ is estimated as:

$$ P_{col} = P(P_{row}) $$

(1)

where $P$ is a local regression model based on Tukey’s bisquare objective function taking into account the preliminary fascia detections contained in the range $[P_{row} - n, P_{row} + n]$, being $n$ expressed by:

$$ n = k \cdot \frac{m}{s} $$

(2)

where $s$ is the distance in mm between consecutive pixels, characteristic of the volume (same in every direction of the volume after interpolation of data), $m$ is the size of the biggest structures to be neglected, also in mm (vessel with largest caliber in the dataset) and $k$ is a constant. This last parameter can be seen as the amount of data which has to be considered to remove the influence of a certain structure. In this work, $m = 5$ was considered, and $k = 5$ was empirically obtained. We used this interpolation method because it is less influenced by outliers. The rightmost column of Figure 3 shows the final segmentations produced by our methodology.

### 3 Results

The Breast Unit of Fundação Champalimaud provided CTA volumes from 20 different patients. For each volume, the end of each perforators and the locations within the DIEAS where the DIEAs perforate the posterior lamella of the abdominal muscle were provided, such that the volumes of interest could be determined. For each axial slice of each volume of interest, a manual annotation of the anterior fascia was performed by an expert. Following the proposed methodology, we obtained 20 fascia segmentations and measured the Euclidean and Hausdorff distances to the corresponding manual annotations. Table 1 shows the mean, best and worst performances achieved.

<table>
<thead>
<tr>
<th>case</th>
<th>E distance (mm)</th>
<th>H distance (mm)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>GT $\rightarrow$ seg</td>
<td>seg $\rightarrow$ GT</td>
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<tr>
<td>mean</td>
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<td>0.51 ± 0.40</td>
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<tr>
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<td>0.28</td>
<td>0.28</td>
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<tr>
<td>worst</td>
<td>1.78</td>
<td>2.15</td>
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</table>

### 4 Conclusion

In this paper, we described a method to segment the anterior fascia of the abdominal muscle, which is relevant for the analysis of DIEP. Intensity thresholding and post-processing are used to obtain a preliminary fascia segmentation. Then, a robust interpolation framework is conducted to produce a smooth detection of the fascia, without interferences from neighbor structures. Our method achieved promising results since it produced segmentations whose mean Euclidean distance to the manual annotations was lower than the distance between consecutive voxels.

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### References


