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A training engine for automatic quantification of left ventricular trabeculation from cardiac MRI

Gregorio Bernabé[1], Javier Cuenca[1], Domingo Giménez[1], and Josefa González-Carrillo[2]

[1] University of Murcia, Spain
{gbernabe,javiercm}@ditec.um.es, domingo@um.es
[2] Hospital Virgen de la Arrixaca, Murcia (Spain)
josegonca.alarcon@gmail.com

Abstract

Based on a software tool proposed for the automatic quantification of the exact hyper-trabeculation degree in the left ventricle myocardium, where the trabecular and the compacted zones are detected, we have designed, developed and tested a training engine for an automatic adjustment of the threshold to identify the trabecular zones and the intensity of the black zone in order to determine the external layer of the compacted zone.

Keywords: non-compacted cardiomyopathy, trabecules, automatic quantification, training engine

1 Introduction

In the last few years, the important technological development in the main cardiologic image techniques, like echocardiography (EC), magnetic resonance (MR) and the multi-slice Computed Tomography (CT) [4], has increased the interest of cardiologists in non-compacted cardiomyopathy, which is characterized by the presence of multiple trabecules in the left ventricle myocardium, associated to multiple inter-trabecular recesses communicated with the ventricular cavity [5][8].

Up to now, there is no firm consensus in the medical community for quantifying and valuing this cardiopathy. Jacquier et al. [7] describe a pioneer work to computationally quantify the trabeculated mass by endocardium delineation. However, the proposed method was applied to a very small number of patients and the classification shown is based on the variables defined previously by the same method.

In [1] we proposed the first automatic software tool based on medical experience that accurately quantifies the LV hyper-trabeculation degree (QLVT), using the cardiac images obtained by magnetic resonance.

Following the same scheme used in previous works [2, 3], the software is improved with the inclusion of a training engine for an automatic selection of the thresholds to identify the

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trabecular zones and the intensity of the black zone in order to determine the external layer of the compacted zone. Therefore, the time needed to complete the process by cardiologists is reduced considerably with respect to the software proposed in [1]. Thus, the training engine provides cardiologists with a support tool for diagnosis that does important work.

The rest of the paper is organized as follows. Section 2 analyses the development of a training engine for QLVT. Experiments to validate the training engine are discussed in Section 3. Finally, Section 4 summarizes and introduces future work.

2 A training engine for QLVT

We propose a training engine for the automatic selection of two essential parameters for the QLVT software: the intensity of the black zone to determine the external layer of the compacted zone, called the intensity threshold `(IT)`, and the threshold to identify the trabecular zones in QLVT, called the trabecular threshold `(TT)`. These two parameters constitute the keys to obtain a successful output that can be accepted by cardiologists in a subjective evaluation to validate the proposed method.

The computing method presented in [1] was applied to 74 cardiac images obtained by magnetic resonance in a population of 11 patients (identified from P1 to P11) with previously diagnosed non-compacted cardiomyopathy and to two control groups of 6 and 5 patients: the first is formed by people with magnetic resonance studies due to other cardiomyopathies, and the second by people with magnetic resonance studies thanks to familiar screening who have been diagnosed as healthy, and so genetically prove negativity. We have classified patients into three groups based on medical experience: `Contrast`, `Darkness` and `Normal` depending on the intensity of the pixels in the LV cavity.

We have built a classifier to determine the group of each input image. In order to perform this classification automatically, for each input image, the classifier computes the Otsu threshold[1] of the whole image and the Otsu threshold of the pixels inside the LV cavity. Both thresholds classify all input images of a patient in one of the three groups. If two classifications of one input image of a patient are equal, this image is classified in the corresponding output. Given a patient, if there is any slice where the two classifications are not the same, the classification for this image is established by the most output obtained in the rest of slices.

Up to now, for each input image, cardiologists established `IT` and `TT`, analyzing the cardiac image several times and adjusting the two thresholds. In this work, we built two theoretical models to accurately obtain the thresholds automatically.

To model the `IT`, we have developed the theoretical model based on equation:
$IT = \alpha_1 * M + \alpha_2 * (M * N) + \alpha_3$, where M is the average of gray scale pixels contained between the left ventricle cavity and the external layer of an input image, as we observe in equation: $M = \frac{\sum_{i=1}^{z} gray_scale_pixel_i}{z}$, where z is the number of total pixels in this zone, and N the normalized average (equation $N = \frac{M}{255}$) of the pixels in this zone, classified in values from 0 to 255 of gray scale.

The values of the coefficients α_1, α_2 and α_3 are obtained with a least-square adjustment. For the `Normal` and `Contrast` groups, α_1 is equal to 0, α_2 is equal to 1 and α_3 is equal to 70. For those groups, the combination of the product of M and N and the addition of the constant α_3 obtains a value that represents a close approximation to the thresholds established

[1] Otsu's algorithm assumes that the image contains two classes of pixels following bi-modal histogram, it then calculates the optimum threshold separating the two classes so that their combined spread is minimal [9].

by cardiologists. For the `Darkness` group, α_1 and α_2 are equal to 0 and α_3 is equal to 80. Therefore, the value of the threshold is fixed to 80 because most of the `Darkness` images use this value.

In a similar way, when modeling the `TT`, the theoretical model is based on equation: $TT = \beta * O$, where O is the Otsu threshold of the pixels inside the LV cavity of an input image.

The value of the coefficient β, is obtained with least-square adjustment. The Otsu threshold can model a parameter that distinguishes trabecular zones composed of grayish or black zones. β is equal to 0.98, 0.90 and 0.88 for the `Darkness`, `Normal` and `Contrast` group, respectively. The three models are needed because the Otsu threshold is normally very close to 255 for the `Contrast` group, a value close to the average of pixels in the left ventricle cavity for the `Normal` group and a value near to 0 for the `Darkness` group.

3 Experiments

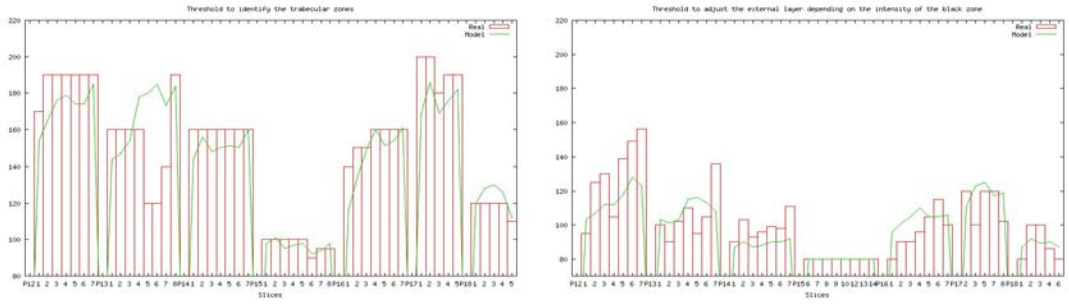
Once 74 cardiac images of 11 patients, presented in the previous section, had been used to build a model, we applied the training engine of QLVT to 46 cardiac images obtained by magnetic resonance to 7 patients (identified from P12 to P18).

All slices of patients P12, P13, P16 and P17 has been classified as `Contrast`, P14 and P18 as `Normal`, and P15 as `Darkness`. Therefore, the classifier obtains a hit rate of 100% and does not commit any errors. For example, for patient P14, 5 slices have the same output classification and for 2 the classification differs, but the number of same classifications is higher than that of different ones and all the slices are classified as `Normal`.

Figure 1 shows the thresholds established by cardiologists and the modeled values of `TT` and `IT` obtained by the training engine of QLVT, for several slices of patients from P12 to P18. Most of modeled values are very close to optimal thresholds. In particular, as shown in Figure 1a, all slices of patients P15, P16 and P18 obtain modeled values to identify the trabecular zones identical to real thresholds. For patients P12, P14 and P17 the modeled thresholds are lower than the real values for the trabecular thresholds, and, consequently, for these slices a lower number of trabecular zones is identified. Finally, patient P13 presents modeled values lower or higher than the real values for different slices, with mass of trabecular zones lower or higher than real outputs. In the same way, as observed in Figure 1b, the tuned values for patient P15 to determine the intensity threshold are identical to the values established by the cardiologist. For patient P14 the modeled thresholds are lower than the real values, implying an identification of the external layer of the compacted zone not so far away from the left ventricle cavity. The rest of the patients obtain modeled thresholds lower or higher than the thresholds established by cardiologists. However, the differences between the real and the modeled thresholds are not important or significant for a visual inspection of cardiologists.

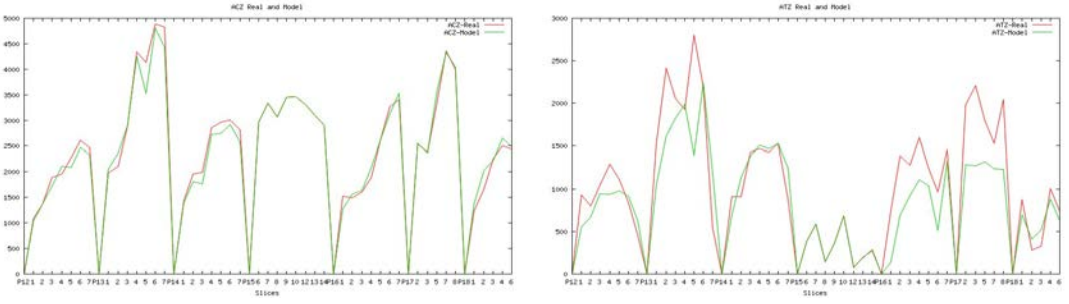
In Figure 2, the area of compacted zone (ACZ) and the area of trabecular zone (ATZ) obtained by QLVT (represented by ACZ-Real and ATZ-Real) and the training engine of QLVT (showed by ACZ-Model and ATZ-Model) are presented for slices of patients from P12 to P18. As we observe in Figure 2a, the ACZ real and modeled are almost identical for all slices of the different patients. Regarding the ATZ, Figure 2b shows that the modeled output is identical to the real values for patient P15 and very similar for patients P14 and P18. For the rest of the patients, the general trend is very similar although in a small number of slices there are some differences. Therefore, the percentage quantification of the trabecular zone modeled is identical or very similar to the real values in all the slices of different patients.

To assess the performance of the training engine of QLVT, a subjective evaluation on the output image with the identified zones was performed by two skilled cardiologists. The images



(a) (b)

Figure 1: (a) Comparison of the real and modelized values for the parameter `TT`. (b) Comparison of the real and modelized values for the parameter `IT`.



(a) (b)

Figure 2: (a) Area of compacted zone (ACZ) computed by QLVT and training engine of QLVT for different slices of patients. (b) Area of trabecular zone (ATZ) computed by QLVT and training engine of QLVT for different slices of patients.

were graded by specialists, using the scale proposed in [6]. For the modeled slices, cardiologists were able to detect the presence of diagnostic features clearly in 76.1% of the evaluated images. In these slices, cardiologists scored with a value greater than or equal to 3.5, which means there is no noticeable difference for diagnosis. Therefore, the training engine of QLVT can obtain very good results without the expert vision of the specialist. Moreover, 10.87% of the modeled outputs were scored at 3, which is very close to an acceptable output by cardiologists. The two modeled thresholds can be adjusted very quickly to obtain a satisfactory output.

The experiments with different types of images reveal that the training engine is capable of detecting and measuring the different zones in different situations, by adjusting the thresholds to detect the trabecular zones and the intensity of the black zone to determine the external layer of the compacted zone. The time needed to obtain the final outputs is less than 2 seconds per image. This time is insignificant compared with the application of QLVT helped by cardiologists or the manual process traditionally used, where cardiologists need from 2 up to 25 minutes per image, to delimit, measure and compute the quotient of the thickness between the trabecular area and the compacted zone.

4 Conclusions and future work

In this work, we have improved the first automatic software tool based on medical experience that accurately quantifies the LV hyper-trabeculation degree [1]. We have added the automatic determination of two thresholds to obtain the external layer of the compacted zone and to identify the trabecular zones. Therefore, we proposed a training engine for QLVT, and significant improvements are obtained with respect to the automatic software tool, so saving valuable diagnosis time of cardiologists.

The time needed to obtain the automatic outputs is less than 2 seconds for each image, obtaining speedups in the range of 60 to 750 with respect to the application of QLVT assisted by cardiologists and manual process traditionally used by specialists.

The training engine is going to be used to quantify the trabeculated mass in $1,150$ patients of a project supported by the Spanish TV3 Marathon Foundation.

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