New Analysis Tools for the Comprehensive Assessment of the Coronary Arteries and Myocardial Viability in CT Data Sets

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Abstract

In recent years the diagnosis of the coronary artery disease is supported by non-invasive imaging methods such as CT, MRI, PET or SPECT. Today, CT is the leading modality for morphology imaging of the heart. Moreover, iodine-based contrast agents enable a visualization of myocardial viability with CT.
In this work, we present new software assistants, that enable a comprehensive result exploration of cause and effect of an ischemia from one imaging modality. Therefore, we adapted our current methods for the detection and segmentation of myocardial scars to CT data and compare the results with measurements from advanced coronary artery analysis. Results on several pig data demonstrate the ability to automatically detect infarctions and to relate them to the causative coronary arteries. Furthermore, preliminary results with two patient data sets illustrate that accurate patient-specific information can be achieved in addition to the standardized AHA 17-segment model.

1. Introduction

Coronary Artery Disease (CAD) is a main cause of death in western countries [1]. Coronary artery stenosis caused by plaque in the vessel wall may impair the perfusion of the myocardium and lead to myocardial dysfunction. As dysfunctional, but viable myocardium has the potential for functional recovery after reperfusion, the tissue state is of great importance for the treatment decision particularly with regard to multi-vessel CAD.
CT is especially suited for coronary tree imaging because of the good spatial resolution (64-slice CT, 0.4mm isotropic). Furthermore, a temporal resolution down to 42ms for 64-slice CT ensures an artifact-free imaging [2]. Tissue viability is assessed by the analysis of the late enhancement effect (LE), which means the accumulation of contrast agent in defective tissue. This examination is normally done by means of MR imaging, however studies have show the feasibility of CT acquisition for tissue stage imaging with iodinated contrast media [3, 4].
There exist a range of methods for multi-modal image registration, which fuse anatomical data from CT with physiological or functional data, e.g. from SPECT [5, 6], or MRT [7, 8]. A first taxonomy for the relation of coronary arteries and corresponding myocardial regions, the so-called AHA 17-segments model, was established to assign each coronary tree segment to a certain left ventricular (LV) muscle segment [9]. The model is also called bull's eye plot (BEP) due to the appearance of its representation. Although, Pereztol-Valdes et al. show the shortcoming of this standardization [10], the model allows a comprehensive overview of quantitative myocardial parameters and corresponding coronary branches.
Moreover, Termeer et al. developed a comprehensive medical visualization framework for a diagnosis-oriented visualization software to explore the combined 2D and 3D data representation of anatomical data and late enhancement analysis results from MRI [11]. Further methods for the relation of coronary arteries from CT and functional results from MRT based on the AHA model are proposed by Oeltze et al. [12]
In this paper we propose new analysis tools for the comprehensive assessment of the coronary arteries and myocardial viability in CT. Based on previous work on comprehensive result exploration [13], we offer a workflow-oriented exploration tool for the comprehensive analysis of CT angiography and LE data.

2. Methods

The proposed software assistants have been developed for the analysis of CT angiographic and late enhancement images. Main aspects are a common data handling concept to enable easy data exchange between the analysis steps. Moreover, adequate visualization and interaction methods allow simple user-guided exploration of result data from all examinations. The structured presentation of the results aims at clarifying the analysis and correspondence infor-

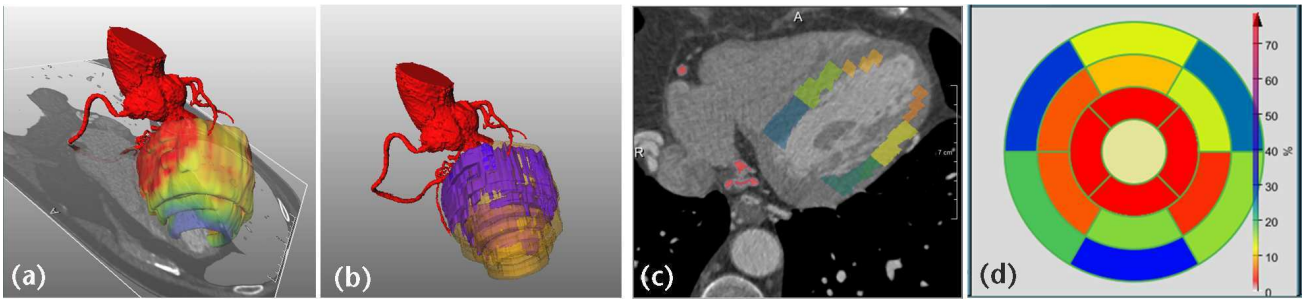

Figure 1. Combined visualization of the 3D representation of anatomical and dynamical information. In 3D either distance of the scar from the myocardium surface is color-coded, whereas the colors range from blue (no scar) to red (high transmurality) (a), or the scar is shown combined with a transparent visualization of the LV myocardium (b). In 2D original CTA data is shown with overlays of the coronary tree segmentation mask (red) and the segment-division of the left ventricle(c). Furthermore, information about the late enhancement portion per AHA segment is shown in the bull's eye plot (d).

mation, which is relevant for the therapy decision. To this end, data-driven user guidance is based on a finding concept that directly relates suspicious positions derived from analysis to the underlying image data.

The following sections provide an overview of the technical aspects of our work. Thereby, we focus on segmentation methods for the coronary arteries and the late enhancement regions. Furthermore, visualization and interaction concepts for the combined inspection of the segmentation results are described.

Segmentation and Analysis. The late enhancement detection starts with a semi-automatic live wire guided segmentation of the myocardium. The intensity distribution of the segmented myocardium is analyzed by fitting a Gaussian Mixture Model with Expectation Maximization [14]. The result of this analysis is combined with a watershed transform and constraints on the location and size of relevant infarctions to achieve the final segmentation. In a further analysis step the late enhancement portions per AHA segment and the center of gravity are determined. The resulting position, the affected myocardial segment, and measurements of the scar ratio are provided as finding information, which is additionally stored to the patient data.

The coronary tree is segmented in the image acquired in the same phase as the analyzed late enhancement image (normally at diastole). After a one-click aorta initialization all exiting arteries are automatically detected [15]. Subsequently, an advanced progressive region growing algorithm processes from the previously found ostium clusters [16]. Based on the segmentation masks a skeletonization is provided, enabling the measurement of the vessel diameter. In case of stenoses the measurements are interactively exported as findings, which collect quantitative values, the position of the detected stenosis and the corresponding coronary tree segment.

Visualization and Interaction. A combined visualization of the coronary arteries, the left ventricular myocardium, and the scar tissue detected by the LE analysis, illustrates the effect of the vessel pathology on the supplied myocardium. To this end, the segmentation results are shown by means of surface renderings in 3D. Related quantitative measurements are represented by color-coding the surface according to common cardiac lookup tables [17]. The same information is shown in 2D within the original image context of either the CTA data or the LE images (cf. Fig. 1).

To focus especially on the exploration of the coherences, which are relevant for the therapy decision, all types of patient-specific data are classified, e.g., as original LE data, masks, or findings. These data-encapsulating classes are related to each other, such that the analysis process can be followed by the dependencies of the data objects. Hence, our methods are integrated into workflow-oriented software assistants using a common data handling framework based on the development platform MeVisLab [18].

All findings can be inspected according to currently selected image data. As they are coupled with bull's eye plot segments, the selection of a certain finding results in a visualization of its position in 2D and 3D as well as the highlighting of related left ventricular segments in the BEP. Thus, measurements of the vessel lumen and possible stenoses based on the centerlines of the segmentation mask are comparable to the late enhancement portion computed within the left ventricular mask. Moreover, corresponding positions are automatically focused in 2D and 3D.

3. Results

The proposed exploration software tool provides a dedicated presentation of the analysis results from different analysis steps. It supports the diagnostic exploration of the morphological and the physiological data. A comprehensive visualization of information about the coronary tree and possible distortions as well as the myocardial tissue

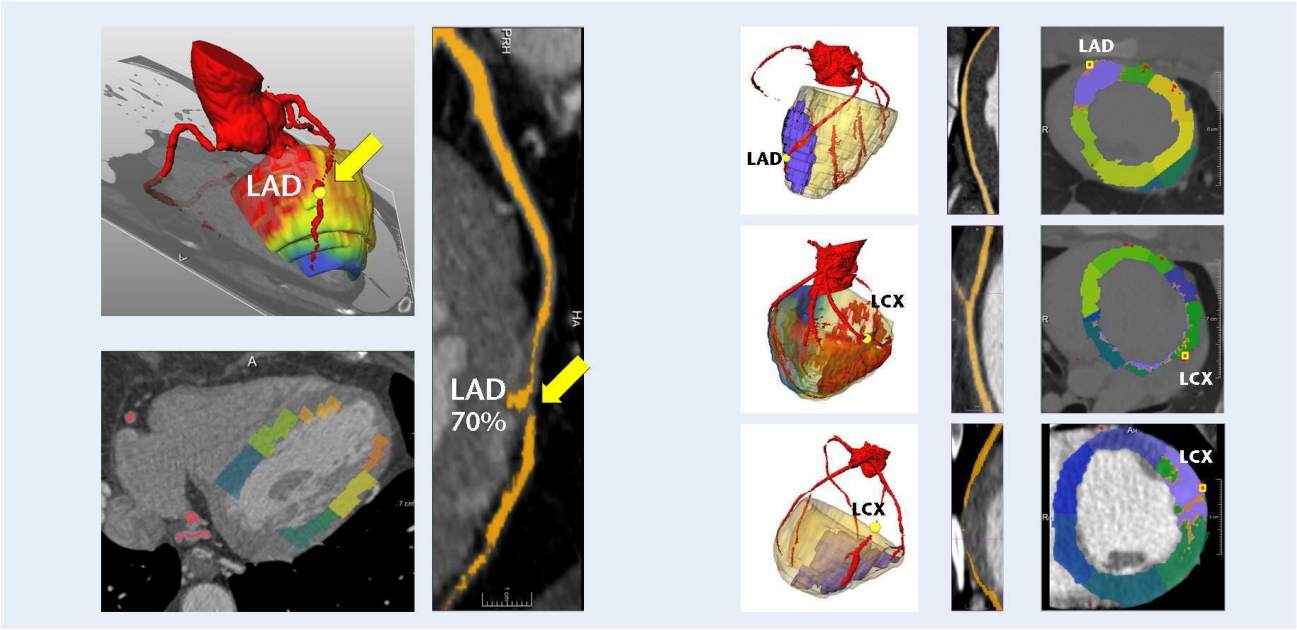

Figure 2. Results for one patient (left) and three pigs (right). The 3D image on the left shows the transmural distance of the scar to the epicardial border combined with the coronary tree and a rendering of the 2D slice for a better orientation. The 3D images on the right show either the distances or the segmentation results for the LV and the scar in combination with the coronary tree. The segment division of the myocardium is shown in the 2D images. Furthermore, a curved MPR of the occluded vessel is shown for all data sets.

state enables conclusions about the disease state and possible treatment strategies.

A first evaluation of the combined analysis of CT angiographic and late enhancement data with respect to a possible treatment strategy was successfully performed on 8 dual-source CT data sets of pigs with reperfused myocardial infarction. For all pigs specified vessel segments were artificially occluded, such that hypoperfused coronary tree branches were a priori known. This allowed a clear assignment of defects and causes as shown in Figure 2, right. The 3D visualizations provide an overview of the coronary tree combined with the myocardium and the scar for three pigs. Each known vessel distortion (yellow marker) can be visually assigned to nearby scar areas (violet). The curved MPR shows the previously occluded vessel and an overlay of the segmentation mask (orange). On the right the original data is shown in 2D with the position of the stenosis, an overlay of the derived myocardial AHA segments, and the segmented scar (violet).

Besides the pig data sets, preliminary results with 2 patient data sets illustrate that accurate patient-specific information can be achieved in addition to the standardized AHA 17-segment model. In Figure 2 on the left, patient data with stenoses in all main vessels is shown, whereas the stenosis degree varies between 70% (LAD), 55% (LCX), and ¿75%(RCA). Even if the scar tissue portion per segment is partly more than 70% for all supplying main vessels, the transmurality information in the distance image shows a hint for the most promising vessel to be treated.

4. Discussion and conclusions

Our software tools allow for a simplified analysis and the correlation of myocardial defects to the vessel causing perfusion deficits (hypodense myocardium on arterial phase images) or even myocardial infarction (delayed contrast enhancement) by advanced visualization. Dedicated interaction methods facilitate a comprehensive exploration of the analysis results, e.g., to relate a narrowed coronary artery with the supplied myocardial area and possibly necrotic tissue. Especially in case of multi-vessel CAD, not all affected vessel branches can be treated. Thus, a road map of all findings including quantitative results supports the therapy decision. The integration of our algorithms into workflow-oriented software assistants allows fast transfer into the clinical practice (cf. Fig. 3). Validation of the correlation between vascular occlusion and myocardial defect was experimentally analyzed on several pig data sets. For human studies such a ground truth is missing and extensive clinical studies are required to show the benefit of this method. Future work will include an incorporation of results from further examinations such as ECG, as well as the implementation of data mining approaches for multiparameter diagnosis support.

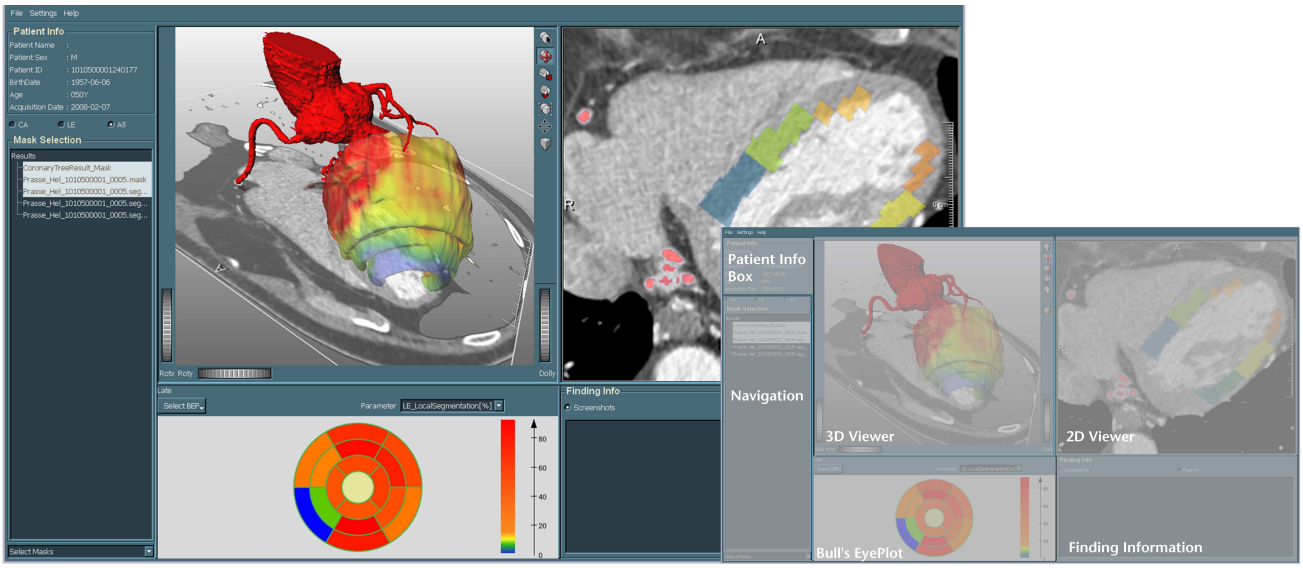

Figure 3. Combination of the coronary tree examination and the LE image. The smaller image on the right illustrates the structure of the software assistant's user interface.

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