Visualization of Coronary Stenosis Plotted on Nuclear Polar Images

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Abstract

The combination of quantitative coronary analysis and flow reserve measurements enables the clinician to determine whether a coronary artery stenosis is significant and therefore has to be treated. To get information on cardiac perfusion, 2-D MIBI SPECT polar diagrams are regarded. However, no real 3-D comparison between the anatomical coronary angiography data and the perfusion information can be made.

In this feasibility study a first approach is made to create fusion images in 3-D of angiograms and SPECT data. From biplane CAGs, both left and right coronary arteries of three patients have been reconstructed as 3-D models. The reconstruction output was automatically converted into VRML scenes. The 2-D polar SPECT data were mapped onto a half-ellipsoid and added to the VRML scene.

Registration of the three models was performed interactively using VRML and common Internet browsers.

1. Introduction

Determination of the clinical and hemodynamic significance of coronary artery stenosis is often very difficult. On one hand imaging techniques like quantitative coronary analysis (QCA) and measurements like fractional- and coronary flow reserve (FFR and CFR) help clinicians to determine whether a stenosis is hemodynamically significant and should be treated, either by PTCA (percutaneous transluminal coronary angioplasty) or CABG (coronary artery bypass grafting). Not only is QCA itself prone to artifacts and large deviations, but also the heamodynamic effect of a specific stenosis on the perfusion in the vessel's drainage area is difficult to assess. The gold standard for the assessment of the severity of myocardial ischemia are nuclear techniques, like single-photon emission computed tomography (SPECT). Myocardial SPECT produces two-dimensional (2-D) polar plots, in which segments correspond with parts of the left ventricle. Matching these plots with the 3-D structure of the coronary vessels however appears to be very difficult.

To get 3-D insight in the myocardial perfusion in correlation with the anatomy, a new method for fusing reconstructed biplane coronary angiography with a 3-D representation of the SPECT data has been conceived and tested and evaluated in 3 patient cases.

2. Methods

The fusion method consists of four phases.

2.1. 3-D angiogram reconstruction

From two simultaneously acquired biplane coronary angiograms (CAGs) of known imaging geometry (BH 3000, Philips Medical Systems, Eindhoven, Netherlands), stored on CD-Medical, both left and right coronary arteries were off line reconstructed as 3-D models. Reconstruction of the 512x512x8bit CAGs (12.5 frames per second) was performed using a previously developed, well-established and validated imaging tool (German Heart Institute of Berlin, Germany) on UNIX workstations (SUN Solaris or HP-UX) [1,2]. The angiographic 3-D reconstruction was performed in the end-diastolic phase of the heartbeat as much as possible, according to the ECG stored along with the angiographic data sets in DICOM. In one case, a 160 ms shift towards pre-end-diastole was applied, in order to get a good reconstruction. Digital acquisition and ECG-gating was used based upon the DICOM standard. The first- and second order branches were extracted from the CAGs semi-automatically. Further branches could have been reconstructed as well, but were omitted for the purpose of clear visualization. Reconstruction was performed in the end-diastolic phase of the ECG. The reconstruction output for both vessel trees was automatically converted into virtual reality modeling language (VRML) scenes.

2.2. 3-D mapping of SPECT plots

Non-gated (with respect to ECG or breathing) SPECT images (Pegasys, ADAC Laboratories, Milpitas, CA), acquired in sessions of approximately 30 minutes, both during stress and in rest, are represented as polar ('bulls-eye') plots. The center third of these 64x64x8bit 2-D polar maps represents the apex of the left ventricle. The remainder is subdivided into five regions of equal thickness and interpolated representing the rest of the left ventricle (see figure 1). In order to compare these data with the angiographic vessel structure, the polar plots were mapped onto a half-ellipsoid, thus approximating the 3-D shape of the left ventricle. This ellipsoid then was modeled in VRML. To create a roadmap for orientation of the SPECT plots, an overlay image, generated by the nuclear imaging system, was mapped first and replaced by the actual plot once correspondence was established.

2.3. Registration of the models

The three VRML models were manually registered in a specially developed tool using platform-independent VRML and JavaScript on common Internet browsers with CosmoPlayer 2.1 software on a 600 MHz Intel Pentium III processor computer under Windows-NT/2000. To be able to compare the results of multiple registrations, following conventions were obeyed: 1. The right coronary tree was not to be scaled or moved. 2. The left coronary tree, that was reconstructed using a fixed magnification ratio with respect to the right, was only to be scaled with this ratio and/or translated or rotated.

The coronary anatomy, defined by both the atrio-ventricular plane and the interventricular plane, was used as a guideline for the vessel tree reconstruction. After positioning the left coronary tree together with the right one, finally the anisotropically scalable half ellipsoid with the overlay image, representing the left ventricle, was placed into the vessel construction.

All subsequent movements of either model were registered and could be undone and redone from any point during the registration. The actual transformation parameters of the three models were displayed and exported into VRML format after a match was found.

The registration functionality is kept in an external-prototype library, thus ensuring efficient reuse of the code across scenes from different patients.

2.4. Output generation

After the registration had been performed, the overlay file was replaced by the appropriate SPECT image of the patient, either in rest or during stress. The three generated VRML files then were combined into a new static VRML scene, from which the clinicians were able to evaluate the myocardial perfusion in relation to the patient's anatomic vessel structure. Additionally, snapshots from a static 3-D scene can be put into the (electronic) patient record. If CFR and FFR results are added, in this way a combination of both functional and anatomical information is obtained.

In figure 1 different phases of the fusion process are illustrated.

3. Results

In this feasibility study, images of five patients who had both undergone biplane CAG and SPECT nuclear imaging were initially selected for image fusion. The patients had had no major cardiac events in between the CAG and the perfusion imaging. The time between angiography and nuclear imaging was 13±6 days.

During the study both the fusion protocol as the registration tool were adjusted and approved. In the initial patient set, one patient's CAG images turned out to be truncated too soon, because of that the identification of the apex would become too inaccurate. Another patient was left out because the left coronary artery could not be reconstructed, and the nuclear imaging mainly represents the left ventricle. This left three patients, on which the protocol was performed. Two were female and the main age was 66±12 years. Of the resulting angiograms, 2 were acquired in a PTCA session, the other one during a diagnostic left/right catheterization session. One patient had undergone previous CABG.

4. Discussion

Earlier studies have shown that image fusion of coronary artery trees with 3-D SPECT images is possible [3], even with automatically superimposition [4]. In this study, the image fusion of X-ray CAG and SPECT perfusion images has proven to be feasible using generally available software tools on medium speed PCs. A more accurate assignment of perfusion regions to focal coronary stenoses can be achieved in this way. However, the method has a number of limitations.

The spatial resolution of the SPECT data is limited. Not only the respiration movement of the patient during the long (about 30 minutes) acquisition, but also the integration of the complete cardiac cycle blurs the images, not only in the long axis, but rotational in the short axis as well. The use of ECG- and respiratory gating during SPECT acquisition would diminish the inaccuracy of the SPECT images and reduce the voxel dimensions. Even with these approvals however, it is known that in polar plots distortions will appear in size, shape and location of perfusion defects.

In the mapping of the overlay image following assumptions were made. The usable surface of the half ellipsoid is restricted to the most 70% towards the apex, i.e., 30% of the long axis beyond the base is not used and remains invisible. This scheme is consistent with the literature on the SPECT polar plot algorithm [5]. In this

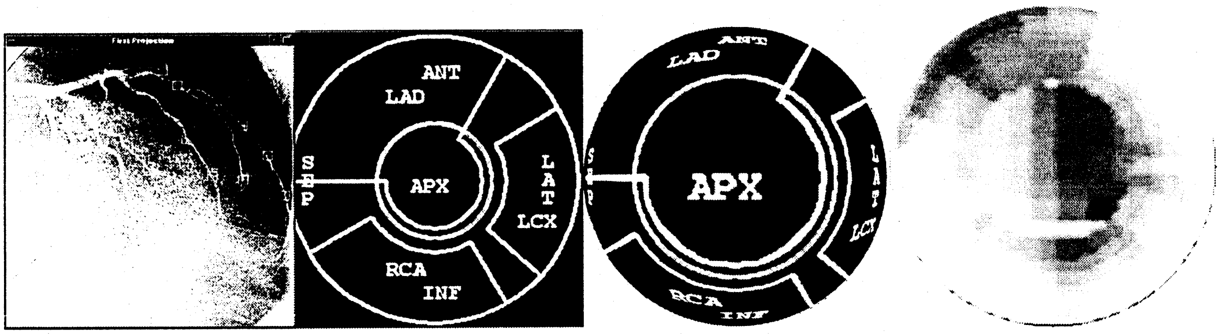

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Figure 1a Screendump of the reconstruction tool , in which a number of points are set (squares) in both views to define the vessel hierarchy and to guide the automated vessel detection.
Figure 1b,c Overlay image produced by the SPECT software (b) and the one used for mapping in an apical projection (c).
Figure 1d Bullseye plot produced by ADAC system.
Figure 2 Screendump of the registration tool. In the upper left-hand corner the relative translation and rotation coordinates of the active scene are displayed. Left in the middle is an interactive orientation 'globe' positioned, to alter the view of the scene on the right. The left-hand bottom corner contains the handle buttons among which a VRML output generation and an undo and redo facility.

usable area, 25% is used for the apex and the other 75% for the rest of the ventricle. Thus the mapping scheme can be regarded as 'rectangular-semi-ellipsoidal' (see figure 1c).

During the internal transformation from raw SPECT data to the polar plots, 3-D anatomical information of the ventricle is lost. To be able to fuse the anatomical vessel structure with anatomical SPECT information, the raw three-dimensional data from the SPECT machine has to be exported. Also volume-rendering techniques could be applied to obtain anatomical scintigraphical perfusion data. However, this was not achieved in this feasibility study. In future research, effort will be put into obtaining these raw data and thus constructing a more realistic left ventricle from the nuclear plots. Nevertheless the perfusion areas of the individual vessels are clearly visible, in spite of the simplifications.

Validation of the described method still has to be performed. Although validation of the 3-D angiogram reconstruction has been performed, the fusion process has to be validated by means of phantoms in a following study.

In order to make the developed tool and protocol more user-friendly, a couple of improvements have been proposed. In the registration phase, the user could have benefit from having an idea where the apex is situated in the reconstructed angiogram. Two possibilities have been taken into consideration, but have not yet been implemented. The apex as well as the plane of the mitral valve could be manually drawn into the 3-D angiographic reconstruction tool, but at this point the tool is not capable to define such 'anchor points'. From the formation of the right and left coronary artery tree, initial guesses can be made of the apex location in both reconstructed models. Placing both apex positions, together with the apex of the approximated left ventricle ellipsoid, at the same initial position, registration might be simplified. In a next version, effort will be put into this extension of the registration tool.

Although the user interface of the registration tool is rather straightforward, it takes quite a learning curve to get used to it. Therefore it is expected that in a larger pilot study the operating times will decrease as users get to better know the software.

A first interoperability comparison showed that the positioning of the artery tree was rather reproducible, however the positioning and especially the scaling of the half ellipsoid did not reproduce as accurately as expected. In a following study with more patients the interoperability will be studied more thoroughly.

Combination of X-ray ventriculography in combination with the angiography was tested as well. The entire ventricle however proved to be too big to reconstruct at once using the same reconstruction software. Little extra information of this combination was found, because the anchor points retrieved from the ventriculogram are specific for the time and place the image was taken, which mostly is quite different from the angiograms. To incorporate ventriculograms in following studies, ventriculograms would have to be incorporated in the angiographic program, which can be done rather easily with patients on which ordinary CAG is performed, but is unlikely to be executed during PTCA.

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