3D Navigator for Localization of Peripheral Coronary Segments by Magnetic Resonance Imaging Angiography

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Abstract

Aim of the study was to assess a new method to follow-up patients with angiographically documented coronary artery disease (CAD), by noninvasive MRI angiography. The method is based on 3D reconstruction of planar cineangiographic images. It is addressed to expand informative content and to extract data from conventional 2D-images, aiming to guide and optimize the use of magnetic resonance for coronary artery visualization. The preliminary tests have shown that it is possible to obtain a fast MRI localization of peripheral coronary segments due to a more precise target volume of scan. This could overcome some limits of MRI examination of coronary tree and expands the use of noninvasive MRI technique in CAD follow-up.

1. Introduction

This research project is placed in the context of magnetic resonance application for a non-invasive diagnosis of coronary pathologies, and particularly of restenosis.

During the last three years Italian, European and American research groups started to experiment the employment of the most innovative magnetic resonance equipments in non-invasive visualization of coronary arteries.

In 1999 Van Geuns et al [1] reported the first attempts to find out a method to identify coronary arteries; they related a good possibility to distinguish proximal coronary segments, but also a wide unpredictability as regards middle distal segments and secondary branches, due to complex morphology of coronary anatomy and cardiac movement.

Throughout the year 2000 the employment of paramagnetic contrast agents optimized by angiography enabled a better view of coronary lumen (Regenfus R. et al [2]). Besides, the introduction of acquisition methods specifically settled to examine both heart and coronary tree, made it possible to enhance the percentage of visible coronary segments. In this field, Van Geuns et al [3] described the acquisition technique of limited volumes via 3D image reconstructions, and working-out enabling a multiplane analysis and the acknowledgment of vascular structures. Several studies have examined the correlation between conventional coronary angiography and coronary angiography with magnetic resonance, to evaluate the presence and severity of coronary stenosis within the shown segments.

Sardanelli et al [4], relate 82% of sensitivity and 88% of specificity; Watunuki et al [5] report 85% of sensitivity and 88% of specificity in serious stenosis (> 90% in conventional angiography); as regards moderated stenosis sensitivity falls to 38% and specificity to 85%. Regenfus et al [2] indicate a sensitivity of 94% and a specificity of 57% for the recognition of the presence of stenotic lesion; Van Geuns et al [3] point out 68% of sensitivity and 97% of specificity.

Nowadays, the actual limit to an extensive employment of magnetic resonance, within non-invasive evaluation of coronary arteries, consists in the difficulty to observe and analyze the whole coronary tree.

At the moment, it is possible to make out proximal segments of mayor coronary branches, while there are poor and unpredictable chances to observe middle and distal parts of coronary branches. Some authors point out a particular difficulty to observe the circumflex artery [2], besides, there are no investigations about secondary branches segments (diagonal branches, marginal branches, descending coronary artery, postero-lateral branches). In case of venous and arterial grafts, the magnetic resonance provides adequate information in 96% of cases (Molinari G et al [4]). Aim of this study is to develop a method for non-invasive angiographic evaluation, by means of magnetic resonance, of patients that previously performed cineangiography. This method is based on 3D reconstruction of planar cineangiographic images in order to guide and optimize the use of magnetic resonance for coronary artery visualization. This could allow a more precise diagnosis of patients with progression of coronary atherosclerosis or with restenosis. This may result in a limitation of inappropriate use of conventional invasive coronary angiography and in a reduction of radiological exposure of patients and medical operators [5,6].

2. Method

Patients with clinical indication to a coronary invasive procedure were selected to enter the study on the basis of their acceptance to undergo magnetic resonance scanning.

First of all diagnostic coronary examinations were performed using the standard Judkins technique, at the end of the study at least two isocentric angiographic sequences were taken in order to obtain data for 3D localization (isocentric means that the heart is placed in the rotation fulcrum of the X-ray tube C-arm). The images were obtained with a flat panel angiographic detector (INNOVA 2000 Cardiovascular Imaging System General Electric Co.), that eliminates lateral distortion artifacts typical of traditional image intensifier TV-chain, with a better signal to noise ratio too. To obtain a large field of view in space, the C-arm must be rotated by a small angle, preferably chosen between 30 and 45 degrees. Hence at the end of the examination we obtain two more sequences. The proposed method is based on the following steps: 1. Image Extraction; 2. 3D Segment Localization; 3. Spatial Coordinate Conversion; 4. MRI Data Acquisition.

2.1. Image extraction

A reference frame in end-diastole is chosen in each of the two extra angiographic sequences, according to the MRI angiography phase image acquisition. Anatomic marker, as side branches, curves, were used for a precise identification of coronary segments. To have a spatial correlation between angiography and MRI at least one anatomic marker is needed. In this experience the left main origin of left coronary artery is the anatomical marker generally used as the common reference between the two image techniques.

2.2. 3D segment localization

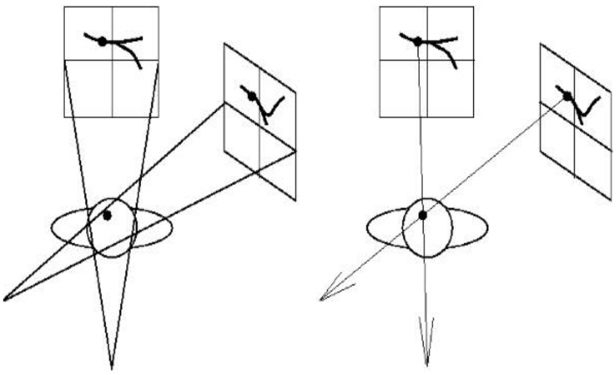

Figure 1. Three dimensional point localization.

To localize coronary segments in the three-dimensional space, data regarding the geometrical configuration of the images is needed, in particular: the angle of X-ray projection; the distance X-ray source to detector; the distance source to isocenter; the dimension of the pixel in mm. All this information is stored in the DICOM standard file of the digital sequences. DICOM is the standard for radiological image archiving and communication, permitting, to store efficiently data along with images in a compact digital format. Spatial coordinates of points of interest are computed finding the intersection between two lines drawn in space. The lines are obtained from the two shot angle acquisitions in isocenter mode. The lines in space are already defined with the starting point in the source of X rays, and the leading points indicated by the operator on the images. We don't need a calibration of the images, because we only need the real coordinates of the vanishing point of the line on the detector plane.

Once the two points in the space are connected by a segment, we find the intersection between these segments, or the point belonging to one segment with the minimum distance to the other segment. This procedure is repeated with the corresponding points indicated by the physician in the two acquisitions. This intersection represents the reconstructed point in 3D coordinates. This geometric reconstruction is done on the assumption of a punctiform source x-ray beam. In Fig. 1 is shown a representation of the reconstruction method, on the left is visualized the projection on the detector from two angles of view, on the right, the coordinates of a point are reconstructed from the two projections.

2.3. Spatial coordinates conversion

To achieve the three-dimensional localization of segments of the artery tree in the magnetic resonance scanner a conversion between the two coordinate systems is needed. The MRI scanner, is a GEMSI Horizon Signa 1.5 T. With this Scanner it is possible to enter the scanning range, in the form of six values, three for the start point and three for the end point. The first step is to make a translation of the points coordinates to the position of the anatomical repere, this is an operation that is needed at the time of MRI scanning due to the variability of the spatial position of the repere in every subject under examination. The second step is to convert the data notation in the one used on MRI scanner. In fact it uses: posterior, left, inferior notation for negative values, and superior, right, anterior, for positive values.

2.4. MRI data acquisition

MRI angiography was performed using a 1.5 T whole body MR scanner (GE, CVi Milwaukee, USA) equipped with high performance gradient (40-mT/m amplitude, 150-mt ms-1 slew rate) and a multi-channel receiver with a maximal bandwidth of 250 kHz. A 4 element (2 anterior and 2 posterior) cardiac phased-array receiver surface coil was used for signal reception. Patients were placed on the imaging table feet first in the supine position with pillow under the knee and feet. 2-D multiphase SSGE sequences were acquired with ECG triggering and breath-hold technique. The sequence parameters were: TR/TE 1071/5.6 msec, flip angle 60°, bandwidth 125 Khz, FOV 24 cm, slice thickness 5 mm, NEX 1, arms 16, Points 4096. Effective spatial resolution was 0.86 mm. The data acquisition was ECG-triggered to mid-diastole using an acquisition window of 14-18 msec depending on cardiac frequency. Before each acquisition a manual optimisation of peak frequency selection on water was performed. To localize the anatomical landmark, three acquisitions: coronal, sagittal, axial scouts were performed. The search of target coronary segments is made by supply scanning range according to spatial coordinates derived from 3D localization.

3. Results

This preliminary experience demonstrated that this method might represent a very quick option to localize and visualize the target coronary segments even in middle distal part of coronary tree. However the planar representations are obtained in fields of view not corresponding to the normal practice of physician. For this reason a 3D MIP reconstruction may be used to obtain a more friendly vision of the target coronary segment.

The proposed method has been tested on five patients. The method is now shown with an example of its application:

First we take the two images from the angiographic sequences (Fig 2) these sequences are obtained with a rotation of 30.7 degrees of the c-arm:

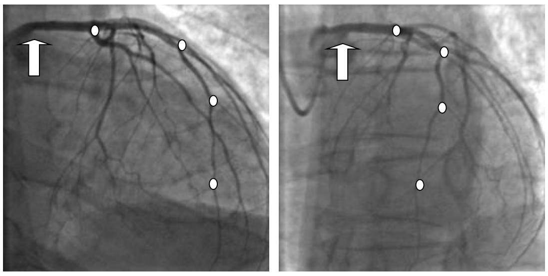

Figure 2. Two angiographic images from the two extra sequences.

The left main landmark is indicated by the arrow in both images, the other white markers indicate the corresponding points of the selected coronary segments in the two views. The planar coordinates of these points analyzed with the developed algorithm give three-dimensional localization of the coronary segment, that in this case resulted in Table 1.

These coordinates are ready for guiding MRI scanning. At the beginning of the MRI scanning three scout acquisitions are made to localize the coordinates of the left main (the anatomical landmark).

Once obtained the coordinates of this landmark, the coordinates of the points are translated in the reference system of the MRI obtaining the Table 2.

The scan procedure is programmed using these parameters as guide for defining the range of scanning.

Table 1. Coordinates in angiographic reference system.

X (mm.)	Y (mm.)	Z (mm.)
33.6	-31.1	414.5
33.2	-14.0	412.7
29.1	10.6	396.2
7.9	26.6	374.2
-24.9	28.0	353.5

Table 2. Coordinates in MRI reference system.

R/L (mm.)	A/P (mm.)	S/I (mm.)
-34.4	28.5	-84.3
-34.7	-13.2	-66
-60.1	-29.3	-44
-92.9	-30.6	-23.3
-34.4	28.5	-84.3

Hence the planar representation images obtained are shown in Fig. 3 and Fig. 4.

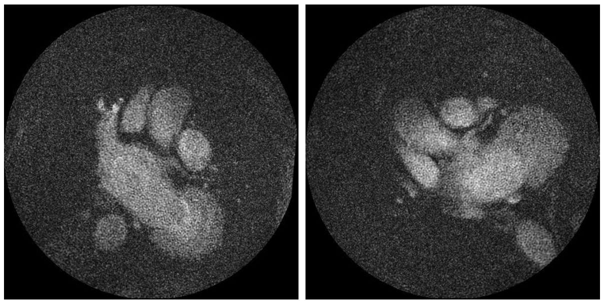

Figure 3. MRI acquisitions of coronary tree.

Figure 4. Another example of MRI acquisitions of coronary tree.

4. Conclusions

The proposed method seems to be a simple, fast and effective way to follow-up non-invasively by MRI the evolution of coronary disease of patients previously submitted to invasive coronary angiography.

This method for 3D localization of the coronary arteries may allow to visualize the middle and distal segments of the main coronary arteries and the secondary coronary branches, that are not visualized with the actual methods of MRI.

References

[1] Van Geuns RJ, Wielopolski PA, de Bruin HG, Hulshoff MD, Oudkerk M, deFeyter PJ. Magnetic resonance imaging of the coronary arteries: imaging planes and resulting anatomy in two-dimensional imaging. Coron Artery Dis. 1999 Oct;10(7):525-31.

[2] Regenfus M, Ropers D, Achenbach S, Kessler W, Laub G, Daniel WG, Moshage W. Noninvasive detection of coronary artery stenosis using contrast-enhanced three-dimensional breath-hold magnetic resonance coronary angiography. J Am Coll Cardiol. 2000 Jul;36(1):44-50.

[3] Van Geuns RJ, Wielopolski PA, de Bruin HG, Rensing BJ, Hulshoff M, VanOoijen PM, de Feyter PJ, Oudkerk M. MR coronary angiography with breath-hold targeted volumes: preliminary clinical results. Radiology. 2000 Oct;217(1):270-7.

[4] Molinari G, Sardanelli F, Zandrino F, Balbi M, Masperone MA. Value of navigator echo magnetic resonance angiography in detecting occlusion/patency of arterial and venous, single and sequential coronary bypass grafts. Int J Card Imaging. 2000 Jun;16(3):149-60.

[5] Vano E, Gonzales L, Fernandez JM, Guibelalde E. Patient dose values in interventional radiology, BR J Radiol 1995, 68:1215-20.

[6] Huyskens, CJ, Hummel WA. Data analysis on patient exposure in cardiac angiography. Radiat Prot Dosim 1995, 57:475-80.

[7] J. Foley, V. Damn, S. K. Feiner, J.F. Hughes. Computer Graphics: Principle and Practice in C (2nd Edition).

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