Feasibility of a Novel Approach for 3D Mitral Valve Quantification from Magnetic Resonance Images

Francesco Maffessanti[1], Marco Stevanella[1], Emiliano Votta[1], Massimo Lombardi[2], Oberdan Parodi[3], Daniele de Marchi[2], Carlo A Conti[1], Alberto Redaelli[1], Enrico G Caiani[1]

[1]Politecnico di Milano, Milan, Italy
[2]Fondazione "G. Monasterio" CNR-Regione Toscana, Pisa, Italy
[3]CNR Institute of Clinical Physiology, Pisa and Milano, Italy

Abstract

The quantitative evaluation of the morphology of the mitral annulus (MA) could have a great impact in both diagnosis and surgical treatment of mitral valve diseases. In this study we aimed at creating a framework for the 3D reconstruction of the MA from CMR cine images.

The developed tool allowed the measurement of several geometric parameters relevant to the MA and the papillary muscles in the 3D space. To test for the repeatability of the measured parameters, CMR datasets obtained from 12 patients with myocardial infarction were acquired, and processed by two operators separately.

Results showed high reproducibility in all the measured parameters. The proposed approach could constitute the basis for a reliable assessment of the MA morphology through CMR imaging

1. Introduction

Quantitative evaluation of the mitral annulus (MA) could have a great impact in both diagnosis and treatment of mitral valve (MV) disease, in particular in case of MV regurgitation due to ischemic or degenerative disease. In fact the morphological characterization of the MV is a crucial aspect for the referral, surgical strategies, and post-operative outcome [1,2].

Although the potentials of cardiac magnetic resonance (CMR) in MA functional evaluation have been reported [3], currently used standard CMR acquisitions are inadequate for accurate and detailed analysis of the MV apparatus, allowing only the measurements of few parameters in 2D space. The steady-state free precession (SSFP) technique allows CMR to be not only a useful tool for the dynamic evaluation of cardiac chambers, using short-axis view, but also for the assessment of MV function, in long axis view. For this reason, due to the high spatial and temporal resolutions, CMR could constitute the ideal imaging technique also for the quantification of several nuances of the valvular apparatus, such as MA and papillary muscles (PMs) function or leaflet geometry.

Aims of this study were threefold: 1) to propose and apply an innovative approach to characterize the MV morphology in 3D space, starting from the acquisition of multiple CMR long-axis SSFP images; 2) once the 3D reconstruction of MA and PMs has been created, to obtain several measurements in the 3D space to characterize MA geometry; 3) to test the reproducibility of the computed parameters.

2. Methods

2.1. Population

A group of 12 patients (8 male, 4 female; age 62±11 years) with myocardial infarction (MI) was considered for analysis. Nine patients had acute MI, while the remaining 3 had previous history of MI. Lesions mainly affected the anterior (4 cases) and antero-lateral (5 cases) walls, rather than the inferior (3 patients). Exclusion criteria were standard contraindications to magnetic resonance imaging. All patients were enrolled at the CNR Institute of Clinical Physiology, Pisa.

2.2. Cardiac magnetic resonance

CMR images were obtained using a 1.5 T Signa Excite (GE Medical Systems) system with a phased-array cardiac coil. SSFP cine images (spatial resolution: 0.78 mm; slice thickness: 8 mm) were acquired in 18 long-axis planes, evenly rotated every 10 degrees along the left ventricular long axis (Fig 1A). Each acquired plane included 55 cardiac phases, with different temporal resolution according to the RR interval of each patient.

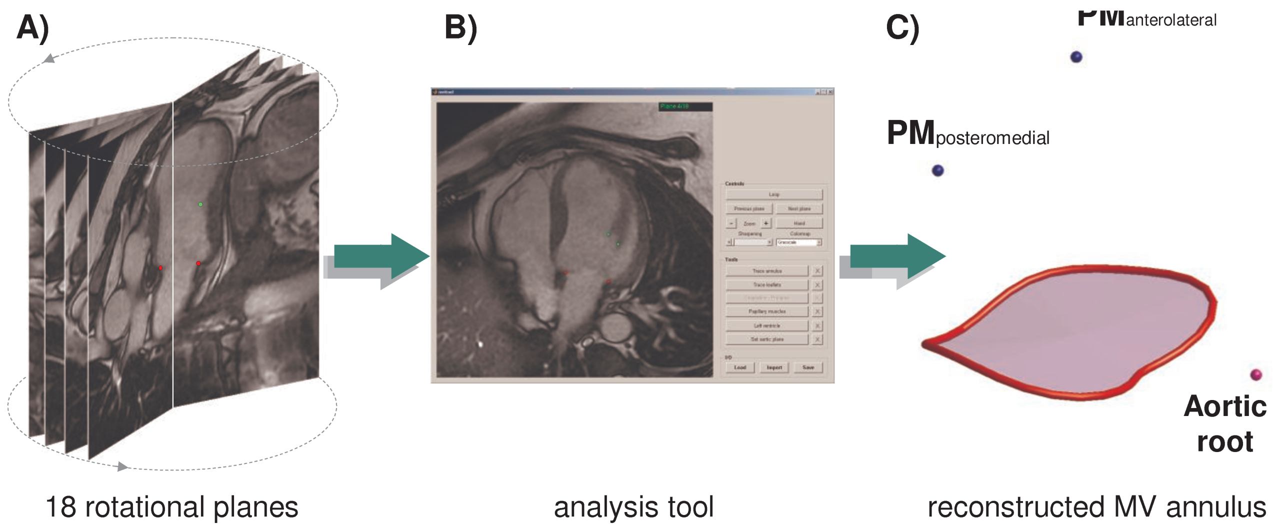

Figure 1. A) schematic representation of the CMR images in a 3D space; B) screenshot of the graphical user interface used to identify mitral valve and papillary muscle position in each plane; C) 3D reconstructed mitral annulus and papillary muscle tips

2.3. Data analysis

Dedicated software was developed in the Matlab environment (Mathworks Inc.) and used for MV quantitative analysis. Briefly, the position of the two MA annular points and papillary muscle (PM) tips, if visible, was manually selected in each of the 18 acquired plane (Fig 1B), both at end-diastole (ED) and end-systole (ES). When this initialization process was completed, the coordinates of the identified MA and PMs reference points were then transformed in the 3D space using the information stored in the appropriate DICOM fields. Finally, the mitral annulus geometry was automatically reconstructed by fitting the reference points using a 5th order Fourier approximating function, while the two PMs tips were located in the 3D space applying a K-means algorithm, as the coordinates of the center of mass of the respective cluster. The 3D annular surface was defined via Delaunay tessellation of the MA reference points (Fig 1C).

Several parameters were then computed on the basis of the obtained 3D model: MA perimeter, antero-posterior (as the axis starting from the saddle horn and passing through MA centroid) and intercommissural (as its perpendicular axis passing through MA centroid) diameters, MA height (as the difference between the saddle-horn and the lowest coordinate of MA points in the direction orthogonal to the MV plane), MA 3D (as the sum of areas of all the mesh triangles along the 3D surface) and projected (as the 2D area computed by geometrically projecting the 3D MA surface on the MA plane) areas and the angle between PMs. Also, the distance from PMs to the MA was defined as the mean distance between the 2 PMs and the MA centroid. The schematic of these parameters is shown in Figure 2.

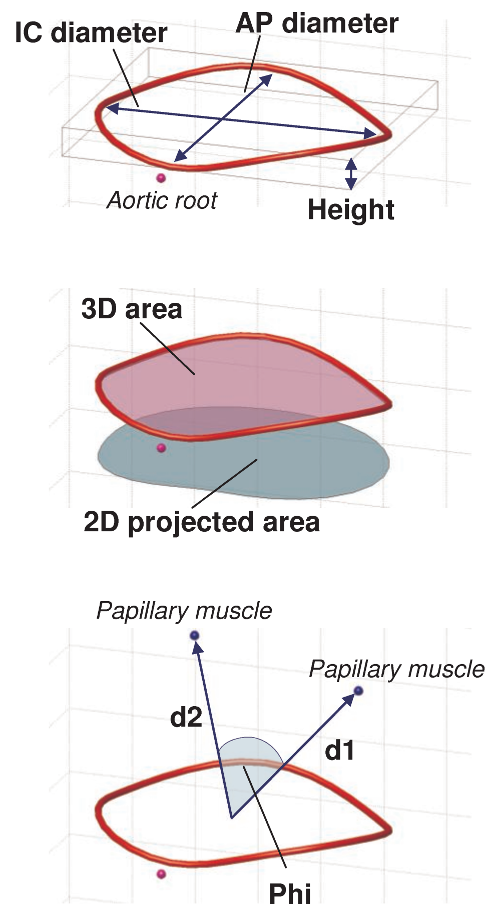

Figure 2. Schematic of 3D mitral annulus and papillary muscles parameters. IC=intercommissural; AP=antero-posterior; Phi=angle between papillary muscles; d1,d2= distance between papillary muscle and mitral annulus

Table 1. Results of mitral annulus analysis in 12 patients with ischemic mitral regurgitation performed by two observers at end-diastole (ED) and end-systole (ES). Values are presented as mean±standard deviation. MA = mitral annulus; PMs = papillary muscles

	Observer A		Observer B	
	ED	ES	ED	ES
MA Perimeter (cm)	11.7±1.3	11.5±1.2	11.8±1.2	11.6±1.1
MA Antero-posterior diameter (mm)	30±5	30±5	31±4	30±4
MA Intercommissural diameter (mm)	39±5	39±4	39±4	38±4
MA Height (mm)	6.8±1.3	6.8±2.1	7.5±1.8	8.0±2.4
MA 3D area (cm^2)	10.0±2.4	9.8±2.3	10.1±2.2	9.9±2.2
MA 2D projected area (cm^2)	9.6±2.3	9.4±2.3	9.7±2.1	9.4±2.2
Angle between PMs (deg)	55±12	44±18	50±12	40±17
Distance between MA and PMs (mm)	33.5±4.2	31.1±4.7	34.1±4.8	31.5±4.6

To assess the reproducibility of the analysis procedure, for each patient two operators blinded to each other performed manual initialization on the 18 planes. The inter-operator variability of the computed parameters was evaluated as the coefficient of variation CV(%)=100*SD/mean).

3. Results

Quantitive analysis of MA was feasible in all patients (100%). The results obtained by the two observers are listed in Table 1, separately for ED and ES.

The proposed method showed a globally good inter-operator agreement (Fig. 3). In details, the MA perimeter (CV_{ED}=1.9%; CV_{ES}=1.8%) as well as the antero-posterior (CV_{ED}=3.0%; CV_{ES}=5.8%) and intercommissural diameters (CV_{ED}=1.8%; CV_{ES}=2.0%) showed minimal variability between the observers. Similarly, both 3D (CV_{ED}=3.4%; CV_{ES} =4.3%) and projected areas (CV_{ED} =2.8%; CV_{ES} =3.7%) were found highly reproducible. On the opposite, MA height (CV_{ED}=9.9%; CV_{ES}=16.1%), the distance from PMs and MA (CV_{ED} =4.1%; CV_{ES} =4.6%) and the angle between PMs (CV_{ED} =6.8%; CV_{ES} =10.6%) show lower levels of inter-operator agreement.

The measurements we obtained are in agreement with those previously published obtained using 3D real-time echocardiography in ischemic or myxomatous valve [4,5], except for the MA height. We may hypothesize that the operator subjectivity in recognizing the correct position of the mitral annulus points in the long-axis view combined with the spatial resolution of CMR, which is comparable to MA height may affect the reliability of the measurement itself. Indeed, MA height was the less reproducible measurement among the considered parameters.

The angle between PMs together with the mean distance between PMs and MA were similar to the values reported by Veronesi et al [6]. Interestingly, parameters relevant to PMs showed a higher variability than MA measurements. This can be explained by the fact that the out of plane motion of the PMs tips introduce a great uncertainty in their accurate location.

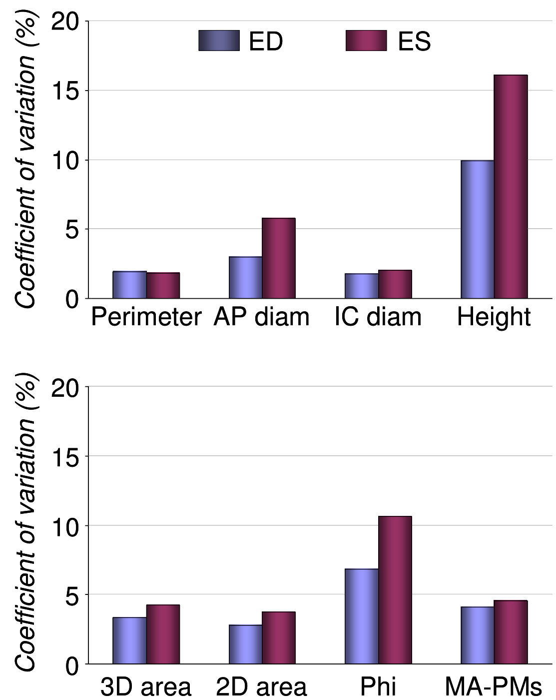

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Figure 3. Bar-graphs showing the coefficient of variation between measurements performed by the two observers. AP = antero-posterior; IC = intercommissural; diam = diameter; MA = mitral annulus; PMs = papillary muscles; Phi = angle between the PMs

4. Discussion

In this work we developed a framework for the quantitive assessment of MA and PMs position. Our findings demonstrated that the analysis of MA and PMs morphology and function is feasible from CMR, when performed in multiple long-axis planes.

The obtained measurements were comparable with those previously obtained using 3D real-time echocardiography in ischemic or myxomatous valve [4,5], except for the MA height. We may hypothesize that the operator subjectivity in recognizing the correct position of the mitral annulus points in the long-axis view combined with the spatial resolution of CMR, which is comparable to 1/10 of the computed MA height, might have contributed to reduce the reproducibility of this measurement. Indeed, MA height was the less reproducible measurement among the considered parameters.

The angle between PMs and the mean distance between PMs and MA were similar to the values reported by Veronesi et al [6]. Interestingly, parameters relevant to PMs showed a higher variability than MA measurements. This can be explained by the fact that the out of plane motion of the PMs tips could have introduced a larger uncertainty in their accurate location.

5. Conclusions

The proposed technique, based on rotational CMR long-axis images acquisition and reconstruction of the initialized points in the 3D space, showed a good reproducibility in the extracted parameters. This approach could constitute the basis for in-depth evaluation of the MV by CMR, with potential application in planning for the best surgical strategy.

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Address for correspondence.

Francesco Maffessanti, MS
Department of Biomedical Engineering, Politecnico di Milano,
Piazza L. da Vinci 32,
20133 Milano, Italy.
Email: francesco.maffessanti@mail.polimi.it