Quantification of Parametric Images to Assess Segmental Wall Motion of the Left Ventricle in Echocardiography

F Frouin[1], C Ruiz-Dominguez[1, 2], T Kalikian[1], N Kachenoura[1], A Delouche[1], A Herment[1], O Nardi[3], B Diebold[1, 4]

[1]INSERM U678, UPMC, Paris, France
[2]Philips Medisys, Suresnes, France
[3]Hôpital Raymond-Poincaré, AP-HP, Garches, France
[4]Laboratoire d'Echocardiographie, Hôpital Européen Georges Pompidou, AP-HP, Paris, France

Abstract

An automated method was developed in echocardiography for defining regional wall motion score (RWMS) using a 4 point scale. Eighty-six time image sequences were analyzed. The left ventricle was divided into 7 segments and the reference RWMS was given by experts. The image sequences were processed by Factor Analysis of the Left Ventricle in Echocardiography (FALVE). Firstly, the FALVE parametric images were visually interpreted. Then a FALVE wall motion index was computed for each segment and a RWMS was deduced. When comparing the scores obtained by the reading of parametric images with the reference RWMS, an absolute agreement, Aa, of 65% a relative agreement, Ar, of 95% and a weighted Kappa coefficient kw of 0.67 were obtained. When comparing the scores obtained by the index with the reference RWMS, Aa of 64%, Ar of 92% and kw of 0.60 were reached. The index is fast and easy to compute, and results in defining RWMS are quite encouraging.

1. Introduction

The regional wall motion score (RWMS) is an important indicator in the detection and the management of coronary artery diseases. Two-dimensional echocardiography is the routine imaging mode to assess this index. Wall motion is routinely assessed visually on cine-loops. However, this approach suffers from inter observer and intra observer variability [1]. To reduce this variability, several methods have been proposed, aiming at quantifying wall motion. Different classes of methods can be distinguished: those based on endocardial wall segmentation (e.g. [2, 3]), those based on Doppler tissular imaging and strain rate imaging [4, 5], those based on optical flow techniques [6, 7, 8], and those based on time variation intensity curves, TVIC [9, 10, 11]. Approaches based on TVIC produce parametric images, which condense the information contained in the sequence of images corresponding to one cardiac cycle. Our approach focused on this last class of methods, due to their ease of use, and to our experience of FALVE methods. An automated approach of classification from the FALVE parametric images has been recently reported [12]. This study aimed at evaluating a slightly modified index on a significant patients' database.

2. Methods

2.1. Patient Database

Eighty-six acquisitions on 49 patients were recorded during at least one cardiac cycle, including 48 four-chamber views and 38 two-chamber views. The full acquisition protocol is detailed in [11]. For each view, three points were manually defined: one at the apex and one at the linkages of the mitral valve. The apical views were then automatically segmented into 7 regions [12], which corresponded to the 17-segment model [14]. This grid was superimposed on the original cine-loop and RWMS was assessed by consensus between two experts using a four point scale: 1 for normal motion, 2 for hypokinesia, 3 for akinesia, and 4 for dyskinesia. This classification was considered as the reference. Low echogenic segments were also reported. Table 1 gives their distribution, NSS being the non scored segments.

Table 1: Distribution of the segments (sg) in the database

WMRS	1	2	3	4	NSS
Number of sg	345	163	60	32	2
low echogenic sg	17%	28%	23%	37%	100%

2.2. Parametric imaging

2.2.1. Preprocessing

According to the results obtained in a recent study [13], some preprocessing steps were systematically applied to the image sequence. Firstly, the images were registered in order to partly compensate for the global motion of the heart, using a simple rigid two dimensional transformation. Then the images were masked in order to restrict the analysis to the left ventricle, the mask being computed directly from the three points defined for the segmentation [12]. This step has proved to be necessary for a correct use of the FALVE algorithm [13]. Finally, the origin of the cardiac cycle was chosen at the closing of the mitral valve, which occurs shortly after the QRS.

2.2.2. FALVE processing

An algorithm of factor analysis was applied using the specific constraints defined for the analysis of the left ventricle motion [11]. It was based on the decomposition of the image sequence as the sum of two separate products: time curve by image. The first curve was nearly flat and the corresponding background image was close to an end diastole image, the second curve was a "bell curve" and was related to the apparent motion from a pixel location; this pattern corresponded to contraction relaxation motion and the corresponding image showed "wall motion", with large positive values on the wall towards the cavity, and negative values on the outside of the cavity.

2.2.3. Visual interpretation of three-color parametric images

The two parametric images were represented in color according to the following convention: the background image in green color, the positive values of the contraction relaxation image in red color and its negative values in blue color. Using this representation, some reading rules were defined [11] to interpret the wall motion abnormalities. This interpretation was based on the width and on the color of the wall band directed towards the cavity (large red for normal, narrow red for hypokinesia, green or red and blue mosaic for akinesia, blue for dyskinesia).

For each acquisition, the two experts read the corresponding parametric image, with the 7 segments superposed on it. A RWMS was then deduced. According to the experts, the interpretation of these images required less time than the interpretation of the original cine-loops.

2.3. FALVE wall motion index

As the interpretation of the parametric images remained visual, and thus subjective, on one hand, as they proved to be relevant on the other hand [11, 13], the definition of an index from these images was attempted in order to make their interpretation automatic.

2.3.1. Index computation

The index was computed from segment profiles derived from the parametric images, as described in [12]. By construction, it was related to the width and the color of the band directed towards the cavity.

The following modifications were introduced to improve the quality of this index. Firstly, as motion amplitude was significantly reduced at the apex, the index was multiplied by two for these segments, in order to make the comparison 'independent' (as far as possible) of the segment location. The normalization parameter was then adapted to low contrast acquisitions. Finally, one threshold was applied in the index computation to remove some artifacts inside the cavity.

2.3.2. Estimation of wall motion abnormalities from the FALVE wall motion index

Three thresholds were defined on the index value in order to classify the segments. Using the reference score, these thresholds were optimized in order to minimize the percentage of misclassified segments, according to the real number of segments in each class.

2.4. Classification performance

Several indices were computed to appreciate the classification performance of the different procedures: absolute agreement was defined as the percentage of segments that were classified without error, frequential absolute agreement was computed for each class as this number divided by the real number of segments belonging to this class.

As the classification scale was graduated, a difference of 1 was less serious than a difference of 2 or 3. Segments for which the classification provided a difference with the reference of 2 or 3 were called bad classified segments. Relative agreement was defined as the percentage of segments that were classified with a difference of 0 or 1. Frequential relative agreement was computed for each class as the number of segments classified with a difference of 0 or 1 divided by the real number of segments belonging to this class. Finally the weighted quadratic Kappa coefficient was also computed.

Moreover, for the 37 patients having both four chamber and two-chamber views, a mean global wall motion score was estimated from the RWMS of the 13 available segments.

3. Results

3.1. Visual interpretation of three-color parametric images

Table 2 gives the contingency table obtained for the visual interpretation of parametric three-color images. An absolute agreement of 65%, a relative agreement of 95%, a mean frequential absolute agreement of 58%, a mean frequential relative agreement of 91% and a weighted kappa coefficient of 0.67 were obtained.

Table 2: Contingency table of WRMS expressed in number of segments (ref: reference interpretation, vip: visual interpretation of parametric images)

	1 (ref)	2 (ref)	3 (ref)	4 (ref)
1 (vip)	238	30	6	0
2 (vip)	88	103	22	6
3 (vip)	7	21	18	4
4 (vip)	2	6	12	21
NC (vip)	10	3	2	1

Sixteen segments were not interpreted by visual inspection of parametric images. Among them, 11 (69%) had been judged low echogenic on the cine-loops. Thirteen (81%) were located at the apex, on the lateral wall or on the anterior wall.

Twenty-seven segments were bad classified, among them, 11 (41%) were low echogenic. Among these 27 segments, 8 (30%) were located at the apex and 10 (37%) at the base (septal segment for four-chamber views and inferoseptal segment for two-chamber views).

3.2. Classification from FALVE wall motion index

The 3 thresholds to separate the four classes were were equal to -1.56, 3.63, and 8.99. Table 3 gives the contingency table obtained for the FALVE wall motion index. An absolute agreement of 64%, a relative agreement of 92%, a mean frequential absolute agreement of 56%, a mean frequential relative agreement of 87% and a weighted kappa coefficient of 0.60 were obtained.

Table 3: Contingency table of WRMS expressed in number of segments (ref: reference, mi: FALVE wall motion index)

	1 (ref)	2 (ref)	3 (ref)	4 (ref)
1 (mi)	261	51	8	4
2 (mi)	66	77	13	4
3 (mi)	13	23	24	4
4 (mi)	5	12	15	20

A total of 46 segments were bad classified. Among them, 13 (28%) were located at the apex and 15 (33%) at the base (septal segment for four-chamber views and inferoseptal segment for two-chamber views). These locations were clearly over represented in the bad classified segments.

3.3. Comparison between the visual interpretation and the amplitude motion index

Moreover, in order to estimate the part due to the imperfections in the computation of the FALVE wall motion index, the classification resulting from the FALVE wall motion index was compared to the classification obtained by the visual interpretation of three-color parametric images. Table 4 gives the associated contingency table. An absolute agreement of 66%, a relative agreement of 98%, and a weighted kappa coefficient of 0.75 were obtained.

Table 4: Contingency table of WRMS expressed in number of segments (vip: visual interpretation of parametric images, mi: FALVE wall motion index)

	1 (vip)	2 (vip)	3 (vip)	4 (vip)	NC (vip)
1 (mi)	231	85	3	0	5
2 (mi)	40	98	14	2	6
3 (mi)	1	32	23	7	1
4 (mi)	2	4	10	32	4

A total of 12 segments (2%) were classified with a difference greater than or equal to 2, showing the main discrepancies between the visual interpretation of parametric image and the computation of the motion index. Among these 12 segments, 6 (50%) were basal segments.

3.4. Global wall motion score

When comparing the scores obtained by the visual interpretation of parametric images with the scores computed from the reference assessment, a good correlation was found (slope of 1.05, Pearson's correlation coefficient of 0.82). The correlation coefficient is smaller when comparing the FALVE wall motion index with the global reference score. However, when excluding the two outliers, a good correlation was obtained (slope of 1.05, Pearson's correlation coefficient of 0.71). Finally, for the 35 remaining patients, the global wall motion score obtained by the score computed from the FALVE wall motion index matched well the score obtained by the visual interpretation of parametric images (slope of 0.99, Pearson's correlation coefficient of 0.82).

4. Discussion and conclusions

This study shows encouraging results regarding the pertinence of the FALVE wall motion index. Indeed, compared to a preliminary work [12], results are obtained using a slightly modified version of the index, and are slightly better than the previously reported ones. Moreover, the FALVE wall motion index is easy to compute, since the only manual intervention which is required is the definition of three points at the apex and at the linkages of the mitral valve.

When compared to the visual interpretation of parametric images, the results of the index are slightly lesser. One explanation is due to the number of segments which have not been interpreted by visual reading. Thus, as these 16 segments are not counted for the calculation of the relative concordance or the Kappa coefficient, these indices may be overestimated. Indeed, the majority of these 16 segments are not echogenic, and 6 are bad classified segments, when using the FALVE wall motion index.

Global wall motion scores indicate the presence of two outlier studies, when using FALVE wall motion index. In one case, two basal segments present a difference of score greater than 2. These segments have not been interpreted by the visual interpretation of the FALVE studies. This case could thus be attributed to an inadequacy of the FALVE method. The other case presents a limitation for the computation of the wall motion index, which tends to overestimate the wall displacement systematically.

A national program enables us to pursue this task of evaluation. In this framework, the EVALECHOCARD project (EVALuation in ECHOCARDiography) has for first objective to increase the patients' database. It will include more than 200 patients. The first half of the clinical database will be devoted to the learning phase, and the second half will be used for the test. The second objective is to test more methods: PAMM [15], and a parietal and regional tracking approach [16] are already involved, in addition to FALVE.

Acknowledgements

The authors thank the French Ministère de la Recherche et Ministère de la Défense (Technovision program).

References

[1] Badano L, Stoian J, Cervesato E, Bosimini E, Gentile F, Giannuzzi P, et al. Reproducibility of wall motion score and its correlation with left ventricular ejection fraction in patients with acute myocardial infarction. Am J Cardiol 1996;78(7):855-858.

[2] Mor-Avi V, Vignon P, Koch R, Weinert L, Garcia MJ, Spencer KT, et al. Segmental analysis of color kinesis images: new method for quantification of the magnitude and timing of endocardial motion during left ventricular systole and diastole. Circulation 1997;95(8):2082-97.

[3] Vignon P, Mor-Avi V, Weinert L, Koch R, Spencer KT, Lang RM. Quantitative evaluation of global and regional left ventricular diastolic function with color kinesis. Circulation 1998;97(11):1053-61.

[4] Heimdal A, Stoylen A, Torp H, Skjaerpe T. Real-time strain rate imaging of the left ventricle by ultrasound. J Am Soc Echocardiogr 1998;11(11):1013-9.

[5] Urheim S, Edvardsen T, Torp H, Angelsen B, Smiseth OA. Myocardial strain by Doppler echocardiography. Validation of a new method to quantify regional myocardial function. Circulation 2000;102(10):1158-64.

[6] Leitman M, Lysyansky P, Sidenko S, Shir V, Peleg E, Binenbaum M, et al. Two-dimensional strain-a novel software for real-time quantitative echocardiographic assessment of myocardial function. J Am Soc Echocardiogr 2004;17(10):1021-1029.

[7] Suhling M, Jansen C, Arigovindan M, Buser P, Marsch S, Unser M, et al. Multiscale motion mapping: a novel computer vision technique for quantitative, objective echocardiographic motion measurement independent of Doppler: first clinical description and validation. Circulation 2004;110(19):3093-3099.

[8] Ledesma-Carbayo M, Kybic J, Desco M, Santos A, Suhling M, Hunziker P, et al. Spatio-temporal nonrigid registration for ultrasound cardiac motion estimation. IEEE Trans Med Imaging 2005;24(9):1113-1126.

[9] Hansen A, Krueger C, Hardt SE, Haass M, Kuecherer HF. Echocardiographic quantification of left ventricular asynergy in coronary artery disease with Fourier phase imaging. Int J Cardiovasc Imaging 2001;17(2):81-8.

[10] Caiani EG, Lang RM, Korcarz CE, DeCara JM, Weinert L, Collins KA, et al. Improvement in echocardiographic evaluation of left ventricular wall motion using still-frame parametric imaging. J Am Soc Echocardiogr 2002;15(9):926-34.

[11] Frouin F, Delouche A, Raffoul H, Diebold H, Abergel E, Diebold B. Factor analysis of the left ventricle by echocardiography (FALVE): a new tool for detecting regional wall motion abnormalities. European Journal of Echocardiography 2004;5(5):335-346.

[12] Ruiz-Dominguez C, Kachenoura N, Mulé S, Tenenhaus A, Delouche A, Nardi O, et al. Classification of segmental wall motion in echocardiography using quantified parametric images. In: Frangi AF et al., editor. FIMH'05. Berlin: Springer Verlag; 2005. p. 477-486.

[13] Diebold B, Delouche A, Abergel E, Raffoul H, Diebold H, Frouin F. Optimization of factor analysis of the left ventricle in echocardiography for detecting wall motion abnormalities. Ultrasound in Med & Biol 2005:in press.

[14] Cerqueira MD, Weissman NJ, Dilsizian V, Jacobs AK, Kaul S, Laskey WK, et al. Standardized myocardial segmentation and nomenclature for tomographic imaging of the heart: a statement for healthcare professionals from the Cardiac Imaging Committee of the Council on Clinical Cardiology of the American Heart Association. Circulation 2002;105(4):539-42.

[15] Ruiz-Dominguez C, Kachenoura N, De Cesare A, Delouche A, Lim P, Gérard O, et al. Assessment of left ventricular contraction by Parametric Analysis of Main Motion (PAMM): theory and application for echocardiography. Phys Med Biol 2005;50(14):3277-3296.

[16] Tilmant C, Sarry L, Motreff P, Geoffroy E, Lusson JR, Boire JY. Detection of myocardium contractility defect by parietal and regional tracking in echocardiography. ITBM-RBM 2005;26(4):282-284.

Address for correspondence

Frédérique Frouin, PhD
INSERM U678, 91 bvd de l'Hôpital, F-75634 Paris cedex 13
France
E-mail address frouin@imed.jussieu.fr