Echocardiographic Evaluation of Left Ventricular Wall Motion using Still-Frame Parametric Imaging

EG Caiani[1,2], RM Lang[2], CE Korcarz[2], JM DeCara[2], L Weinert[2], KA Collins[2], KT Spencer[2], S Cerutti[1], V Mor-Avi[2]

[1]Dipartimento di Bioingegneria, Politecnico di Milano, Milano, Italy

[2]Noninvasive Cardiac Imaging Laboratory, University of Chicago, Chicago, Illinois, USA

Abstract

We tested the feasibility of improved evaluation of left ventricular (LV) wall motion using still-frame parametric images of local videointensity oscillations. In 8 anesthetized pigs, baseline parametric images showed bright bands in the area spanned by endocardial motion, which gradually decreased in brightness and thickness in the territory of the occluded coronary artery. In 30 patients with contrast-enhanced echocardiograms, "gold standard" for wall motion was determined from independent interpretations of dynamic images made by three experienced reviewers. Dynamic images were independently classified by 3 inexperienced and 3 intermediate experience level readers. Interpretation was then repeated in combination with parametric images. Compared with the "gold standard", evaluation of wall motion correlated with the readers' experience and was significantly improved by adding parametric images.

1. Introduction

Clinical echocardiographic evaluation of regional left ventricular (LV) wall motion is based on visual interpretation of dynamic two-dimensional images of the heart, which is subjective [1] and experience dependent [2]. Moreover, the evaluation of regional wall motion can be even more difficult in patients with poorly visualized endocardium, in whom contrast agents are used to enhance the endocardial border [3]. In these patients, the development of techniques complementary to visual interpretation of dynamic images might improve the diagnostic value of the echocardiographic evaluation of LV wall motion.

We hypothesized that still-frame parametric images representing the amplitude of periodic changes in pixel intensity could provide objective information on LV wall motion in the area spanned by endocardial displacement during the cardiac cycle. Accordingly, the aim of this study was to develop and test the feasibility of a new technique based on parametric imaging of endocardial motion, which would be applicable to echocardiographic images obtained with or without contrast enhancement. We initially used an animal model of acute ischemia to determine whether this technique is sensitive enough to track ischemia-induced wall motion abnormalities. A subsequent protocol was carried out in patients with poor acoustic windows who required LV opacification to visualize endocardial motion. This protocol was designed to determine whether the use of parametric images in combination with dynamic images could improve the accuracy of wall motion interpretation, particularly by less experienced echocardiographers.

2. Methods

2.1 Protocol 1

Experiments were carried out in 8 male farm pigs (21-26 kg). Pigs were mechanically ventilated (Drager, Telford, PA) and anesthetized with isoflurane. An intracoronary balloon catheter (2.5 to 3.5 mm balloon diameter) was introduced into the left anterior descending (LAD) coronary artery under fluoroscopic guidance. Balloon size and pressure necessary for complete coronary occlusion were determined by angiographically assessing distal coronary flow during intracoronary injections of renografin.

Transthoracic parasternal short axis images (SONOS 5500, Agilent Technologies, Andover, MA) were obtained using an S3 probe at the level of the papillary muscles in the integrated backscatter (IBS) mode at 30 frames/sec. Settings were kept unchanged throughout the experiment to eliminate gain dependency.

Continuous image acquisition was performed under control conditions, 5 and 60 sec after complete coronary occlusion, and within 30 sec after balloon deflation, during reperfusion. To minimize cardiac translation, the ventilator was stopped at end-expiration during each image acquisition. All image sequences were acquired digitally and stored on magneto-optical disk for off-line review and computer analysis.

2.2 Protocol 2

Thirty adult patients (age 64±14 years) with inadequate endocardial visualization in at least two contiguous segments, were enrolled in this protocol. Parasternal short-axis and apical four-chamber views were obtained in the IBS mode at 30 frames/sec. Contrast enhancement was achieved using 0.5 ml intravenous bolus injections of Optison (Mallinckrodt Medical). Images were continuously acquired during held end-expiration over one cardiac cycle and stored digitally on magneto-optical disk.

2.3 Construction of parametric images

Digital IBS images were first cropped to isolate the LV cavity and the surrounding myocardial tissue. Pixel values were extracted throughout the cardiac cycle to create time series of videointensity, which were then fitted into a sinusoidal function with the period defined by the cardiac cycle duration. A parametric image was then created by displaying in each pixel the amplitude of the best fit function divided by its mean value. This analysis was implemented using custom-made software.

2.4 Data analysis

In protocol 1, the effects of coronary occlusion were judged by visual examination of the dynamic and parametric images.

Dynamic IBS images obtained in protocol 2 were independently reviewed by three experienced echocardiographers who classified each segment as non-visualized endocardium, normal or abnormal wall motion, according to [4]. For each segment, the "gold standard" was defined as the concordant interpretation of at least 2 out of 3 readers. The inter-observer variability was calculated as the percentage of segments where the interpretation of one of the readers was different from that of the other two. Subsequently, the dynamic IBS images were independently classified by two groups of three readers each: inexperienced (ASE level I of training), and intermediate experience level (ASE level II of training) [5]. The individual interpretations were compared to the "gold standard" by counting the segments where concordant (true positive and true negative) and discordant (false positive and false negative) interpretations were made. The classification of segmental wall motion was then repeated by the same readers in a separate session, reviewing the dynamic loops in combination with parametric images. For each group of readers, segment counts were used to calculate the sensitivity, specificity and accuracy of their readings against the "gold standard" expert interpretations. Individual readings were analyzed to obtain the inter-observer variability in each group. The improvement in sensitivity, specificity, accuracy and inter-observer variability achieved by adding parametric images was tested for each group of readers using the Z-test with Yates correction and considered significant for $p<0.05$.

3. Results

Figure 1 shows an example of end-systolic (A) and end-diastolic (B) IBS images obtained in a pig under control conditions (top panels) and in a normal human subject (bottom panels), with overimposed manually traced endocardial boundaries. Analysis of images obtained throughout the cardiac cycle resulted in a parametric image of normalized local videointensity oscillations (C). We found that the amplitude of oscillation (D) in most pixels in the area contained between the end-systolic and end-diastolic contours (i.e., where endocardial motion occurred) was higher than outside this area. This was a result of IBS intensity changes from low values typical of blood in diastole to high values typical of tissue in systole in pigs, and from

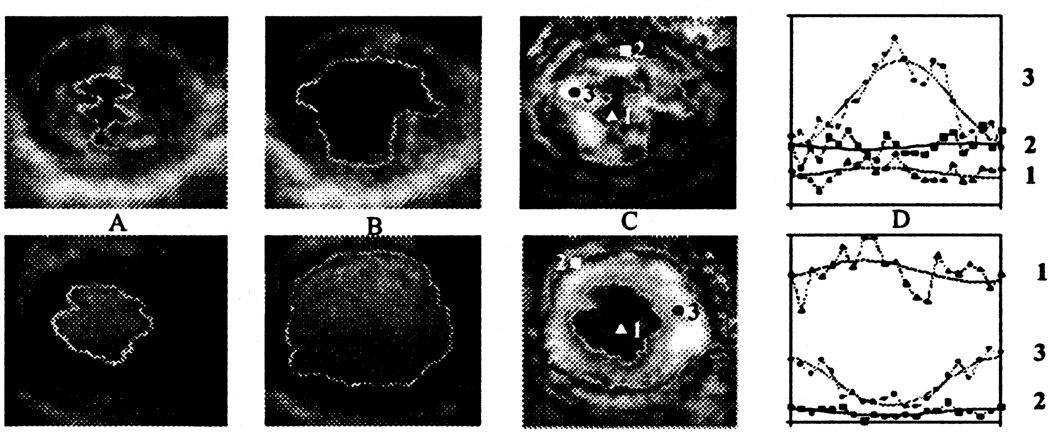

Figure 1. Example of end-systolic (A) and end-diastolic (B) IBS images and the parametric image of local videointensity oscillations (C) obtained in a pig (top panels) and in a contrast-enhanced human subject (bottom panels), with manually traced endocardial boundaries superimposed. Videointensity values over time and their first harmonic fitting for pixels positioned in different places (1-LV cavity and 2-myocardial tissue in all frames; 3-both) are shown in panel D.

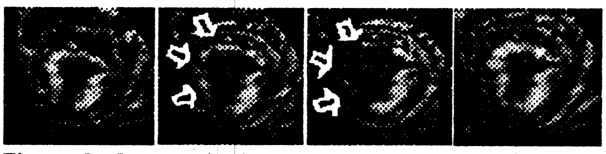

Figure 2. Parametric images obtained in a pig under control conditions, 5 sec and 60 sec post LAD occlusion, and during reperfusion (from left to right respectively).

high values, typical of contrast enhanced LV cavity in diastole, to lower values, typical of myocardial tissue in systole in humans. Consequently, in the parametric images, (C) this area appeared as a bright band surrounding the LV cavity.

Figure 2 shows an example of parametric images obtained in a pig during the different experimental phases. The intensity and thickness of the bright band visualized in the control image gradually decreased as a result of coronary occlusion, reflecting the developing hypokinesis in the LAD territory. During reperfusion, both the thickness and intensity of the bright band increased above their control levels, reflecting hyperdynamic function. These changes were observed in all animals during ischemia and reperfusion phases.

Out of 360 segments (180 in each view) analysed in 30 patients, 234 were interpreted by the expert readers as normal, 118 as abnormal and 6 were not visualized. The remaining two segments were excluded from further analysis, due to divergent interpretations among the three experts. According to the "gold standard", out of the 30 patients enrolled in this protocol, 13 had regional wall motion abnormalities, 5 had global hypokinesis and 12 had normal wall motion. The inter-observer variability of the expert interpretation of wall motion was 16%.

Figure 3 presents three examples of short-axis and apical-four chamber parametric image obtained in a patient classified as normal, characterized by a continuous bright band reflecting normal wall motion, a patient with inferior and septal akinesis and a patient with dilated cardiomyopathy, where the overall thickness of the bright band is minimal reflecting global hypokinesis.

Table 1. Interpretation of regional endocardial motion by readers at different experience levels (A – inexperienced, B – intermediate experience) calculated against expert readers' "gold standard" interpretations. To assess the benefit of adding parametric images, each group of readers reviewed dynamic IBS images without and with (+P) parametric images (*: p<0.05).

	Group A		Group B	
%	IBS	IBS+P	IBS	IBS+P
Sensitivity	86	87	90	86
Specificity	59	83*	89	96*
Accuracy	68	83*	88	91
Inter-observer variability	54	32*	21	12*

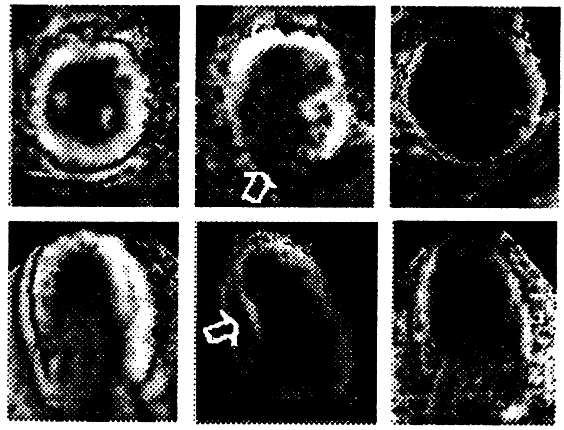

Figure 3. Examples of parametric short-axis (top) and apical 4-chamber (bottom) images obtained in patients: with normal wall motion (left), with regional wall motion abnormalities (center), and with global hypokinesis secondary to dilated cardiomyopathy (right).

Table 1 presents the sensitivity, specificity, accuracy and inter-observer variability data calculated for each group of readers of dynamic IBS images with and without parametric images. Adding parametric images to the dynamic loops significantly improved the accuracy of interpretation by inexperienced readers, as well as the specificity in both groups. Moreover, the inter-observer variability was significantly reduced by combined reading of dynamic and parametric images in both groups of readers.

4. Discussion

The goal of this study was to develop a new tool that would quickly and automatically create single still-frame images of endocardial motion, as a helpful adjunct to the conventional technique for the assessment of regional LV function. Our hypothesis was that this display, when combined with dynamic images, might improve the accuracy and reduce the inter-observer variability in the interpretation of LV wall motion made by less experienced readers.

We chose the normalized amplitude of local videointensity oscillations as the parameter to be displayed, based on the hypothesis that pixel transitions between blood and tissue would generate very strong periodic changes in backscatter intensity in the area spanned by the endocardial motion over the cardiac cycle. We expected these changes to be significantly lower in other portions of the image. This assumption was indeed confirmed in both patients (with contrast-enhancement) and animals (without).

We also found in both the short-axis and apical four-chamber views that parametric images maintained the morphologic features of the heart, thus allowing the reader to easily identify the location of the detected wall motion abnormalities. Since the analysis of individual pixel intensity variations over time is very sensitive to speckle noise inherent to most ultrasound imaging modes, we chose IBS images as the raw data for parametric imaging because of the relatively low level of speckle noise that allows parametric images to be generated automatically and quickly (within 1 min).

The ability of this technique to reflect changes in regional wall motion was initially tested in an animal model of acute ischemia and reperfusion. These changes were judged by visual examination of the parametric images and confirmed the hypothesis that parametric images indeed provide a simple still-frame display of endocardial motion, sensitive enough to visualize ischemia-induced regional hypokinesis.

In protocol 2, we tested the feasibility of applying our technique to IBS images obtained in human subjects with poor acoustic windows, representing the main target population of new techniques designed to aid in the assessment of wall motion. To determine the usefulness of this approach, the combined use of dynamic IBS and parametric images was compared with the review of dynamic images alone, by calculating the accuracy and reproducibility of the proposed technique at different level of experience. Although contrast-enhanced IBS images are not the standard for the evaluation of LV wall motion, the review of these images by experienced readers resulted in inter-observer variability of 16%, which was comparable with the variability of 13.5% in the conventional interpretation of regional systolic wall motion based on good quality B-mode scans [6].

Our results confirmed the importance of experience in the visual interpretation of LV wall motion based on review of dynamic images [2] by demonstrating clear differences between the accuracy of readings made by different reviewers participating in this study. The accuracy and mainly the specificity of reading were improved by adding parametric images, despite the non-significant decrease in sensitivity for readers with intermediate level of experience. Interestingly, with the aid of parametric images, the inexperienced readers were able to reach the accuracy level similar to that of more experienced echocardiographers.

4.1 Limitations

Similar to any new imaging technique, interpretation of parametric images requires initial learning and basic understanding of the information displayed. The main limitation of this technique is its high sensitivity to noise that may be caused by cardiac translation or by the presence of the papillary muscles in the imaging plane during part of the cardiac cycle, especially in the apical views. To minimize translation-related artifacts, images were acquired in pigs with the respirator turned off and in patients at held end-expiration. For these reasons, parametric images should not be attempted to replace the conventional visual interpretation, but rather to supplement it with an additional still-frame display, which was found to be useful and easier to interpret.

This approach was tested in a relatively small number of patients, and accordingly needs to be thoroughly studied in a larger group of subjects. In particular, future studies will include undergoing echocardiographic stress-testing, where the assessment of regional wall motion is even more difficult, and the additive benefits of our technique would be potentially more significant.

5. Conclusion

The results of this study proved the feasibility of a new technique for still-frame parametric imaging of endocardial motion. This technique was found to be reproducible and sensitive enough to detect ischemia-induced changes in a closed-chest animal model, as well as to accurately diagnose wall motion abnormalities in patients with poor acoustic windows who required LV opacification to visualize the endocardium. When combined with dynamic images obtained in humans, this technique has the ability to improve the accuracy of the interpretation of LV wall motion by less experienced echocardiographers, and has the advantage of being more objective than the conventional methodology.

References

[1] Popp RL, Agatston A, Armstrong WF et al. Recommendations for training in performance and interpretation of stress echocardiography. J Am Soc Echocardiogr 1998;11:95-6.

[2] Picano E, Lattanzi F, Orlandini A, Marini C, L'Abbate A. Stress echocardiography and the human factor: the importance of being expert. J Am Coll Cardiol 1991;17:666-9.

[3] Cohen JL, Cheirif J, Segar D et al. Improved left ventricular endocardial border delineation and opacification with Optison (FS069), a new echocardiographic contrast agent - Results of a phase III multicenter trial. J Am Coll Cardiol 1998;32:746-52.

[4] Schiller NB, Shah PM, Crawford M et al. Recommendations for quantitation of the left ventricle by two-dimensional echocardiography. J Am Soc Echocardiogr 1989;2:358-67.

[5] Stewart WJ, Aurigemma GP, Bierman FZ et al. Guidelines for training in adult cardiovascular medicine. Core Cardiology Training Symposium (COCATS). Task Force 4: training in echocardiography. J Am Coll Cardiol 1995;25:16-9.

[6] Lang R, Vignon P, Weinert L et al. Echocardiographic quantification of regional left ventricular wall motion using Color Kinesis. Circulation 1996;93:1877-85.

Address for correspondence.

Enrico G Caiani, PhD
Dipartimento di Bioingegneria, Politecnico di Milano
P.zza L. da Vinci, 32 – 20133 Milano - Italy
caiani@biomed.polimi.it