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Quantitative analysis of segmental left ventricular wall motion using a polar representation of color kinesis images

Avaliação quantitativa da mobilidade segmentar do ventrículo esquerdo utilizando uma representação polar das imagens de "color kinesis"

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Abstract
Color Kinesis (CK) is a technique developed to display timing and magnitude of global and regional left ventricular wall motion (LVWM) in real time. In this study, we describe a new method for representing CK images in polar maps to provide an integrated and objective evaluation of LVWM. We evaluated normal subjects and patients presenting LVWM abnormalities on two-dimensional echocardiography to verify the ability of this method for providing automated identification and quantification of LV systolic dysfunction. The results show that, although polar representation of CK images is feasible and can provide quantitative, segmental and global evaluation of LVWM, this image-processing tool has shown a relatively limited ability for automated identification of left ventricular dysfunction as compared to LVWM analysis by experienced observers.
Keywords: Color Kinesis, Image Processing, Left Ventricular function.

Resumo
A "color kinesis" (CK) é uma técnica que representa o tempo e a magnitude da mobilidade global e segmentar do ventrículo esquerdo (MSVE) em tempo real. Neste estudo descreve-se um novo método para representar estas imagens na forma "bulls-eye" em mapas polares que provêem uma avaliação integrada e objetiva da MSVE. Foram avaliados indivíduos normais e em pacientes apresentando anormalidades na MSVE no estudo ecocardiográfico bidimensional com o objetivo de verificar a capacidade desta técnica para identificar e quantificar automaticamente a disfunção ventricular. Os dados obtidos demonstram que, embora a representação polar de imagens de CK seja factível em uma elevada proporção de indivíduos e possa proporcionar uma avaliação quantitativa da MSVE mais objetiva e menos dependente do operador, essa ferramenta de processamento de imagens mostrou limitada capacidade para identificação automática de disfunção ventricular quando comparada com a análise de observadores experientes.
Palavras-chave: *Color Kinesis, Função Ventricular Esquerda, Processamento de Imagem.*

Introduction

In the clinical setting, the evaluation of regional left ventricular wall motion by two-dimensional echocardiography is traditionally based on visual analysis of myocardial thickening and endocardial motion. This assessment is subjective, highly dependent on the observer experience and the results obtained are semi-quantitative. On the other hand, the first quantitative methods described for left ventricular systolic function were based on off-line manual tracing of endocardial borders and on geometric assumptions to estimate left ventricular volume (Assmann *et al*., 1990; Force *et al*., 1984; Gillan *et al*., 1984; Ginzton *et al*., 1986; Moynihan *et al*., 1981). These techniques are time-consuming; in addition they remain subjective and dependent on observer expertise.

A number of computerized methods have been developed for automated edge detection of endocardial borders (Buda *et al*., 1983; Garcia *et al*., 1981; Geiser *et al*., 1990; Perez *et al*., 1992; Perez *et al*., 1992a; Schnittger *et al*., 1984). Acoustic quantification (Perez *et al*., 1992; Perez *et al*., 1992a) is an automated edge detection method incorporated into a commercially available ultrasound system, which provides real-time, objective and reproducible estimation of ventricular area and volume (Chenzbraun *et al*., 1993; Gorcsan *et al*., 1993; Gorcsan *et al*., 1993a; Marcus *et al*., 1993; Morrissey *et al*., 1994; Perez *et al*., 1992; Perez *et al*., 1992a). Color kinesis is a technique (Lang *et al*., 1996), based on acoustic quantification, and developed to display on-line timing and extension of endocardial motion by creating a color map of regional wall motion. Despite its potential for clinical application (Husic *et al*., 2005; Takeuchi *et al*., 2003), there are few studies analyzing the quantitative information included into color kinesis images.

This investigation was performed to: 1) develop a computerized method for quantifying the relative extension of segmental systolic endocardial motion as documented by color kinesis and for providing an integrated and quantitative representation of global and regional left ventricular wall motion as a polar map or "bulls-eye" view; 2) analyze the pattern of left ventricular segmental wall motion in normal subjects and patients with left ventricular dysfunction; 3) evaluate the ability of this image processing tool for automatically identify regional left ventricular dysfunction.

Methods

Subjects

Color kinesis images were obtained in 23 normal subjects (8 women, 15 men), aged 23 to 61 years (mean 30), who were completely asymptomatic and presented a normal two-dimensional echocardiogram, and 21 patients (4 women, 17 men) aged 24 to 79 years (mean 53) who had segmental or diffuse left ventricular dysfunction as documented by two-dimensional echocardiography. Two normal individuals were excluded due to inadequate 2D and color kinesis image quality caused by inappropriate acoustic window in thorax. Patients were included considering: 1) adequate image quality (2D and endocardium tracking by acoustic quantification); 2) sinus rhythm; 3) presence of wall motion abnormalities exclusively related to ischemic or myocardial disease. All subjects who were included in this investigation provided informed consent.

Equipment and data acquisition

This investigation was performed using a commercially available ultrasound system (Philips Sonos 5500) which included the acoustic quantification and color kinesis software packages. Images were obtained with subjects in left lateral decubitus position, using a 2 to 4 MHz transducer. After a complete conventional two-dimensional echocardiographic study, the acoustic quantification software was activated and adjusted to obtain adequate tracking of endocardial borders. Color kinesis images were then obtained and recorded into an optical disk.

Acoustic quantification technique provides frame-by-frame endocardial border detection based on the comparative analysis of intensity of the received ultrasound signal to a pre-established threshold set by manufacturer to distinguish tissue from blood. Therefore, received signals are classified as blood or tissue if they had, respectively, lower or higher intensity than the established threshold. Color kinesis represents an on-line color encoding of endocardial excursion throughout cardiac cycle. The variable position of the endocardial border during cardiac cycle is tracked and represented as different color hues, triggered from end-diastole and displayed at 33 ms intervals. At end-systole, the colors added during systole frame-by-frame, result in a color overlay composed by each 33 ms display, which express the timing and magnitude of endocardial excursion throughout systole.

CK images were obtained in two sets: 1) apical views (longitudinal, two and four chamber); 2) paraesternal short axis views (at mitral valve, papillary muscles and apical levels). For each imaging plane, two systolic images were obtained, stored into an optical disk and downloaded into a personal computer where all calculations and processing were performed. The first of these image planes is parallel to the long axis of

the left ventricle, while the other one is perpendicular to this axis (Figure 1).

Based on these two sets of images it was possible to define 16 segments of the left ventricle as standardized by the American Society of Echocardiography (Schiller *et al.*, 1989), for each imaging plane. The color kinesis images were then used to develop a polar representation ("bulls-eye" format) of left ventricular systolic function including, in each imaging plane, all 16 segments documented. It is worth to note that each ventricular segment was represented in both polar maps, in two different planar orientations, i.e. short axis and long axis planes (as seen in Figure 1). In the "bulls-eye" representation of left ventricle, the more external segments correspond to the basal portion of ventricle while the central segments represent the apical region of left ventricle (Figure 2).

Image segmentation and segmental analysis of endocardial motion

Color-encoded images were divided into segments using custom software. In a first step, a binary image was extracted from the original image, where colored pixels were assigned as true or value "1", while gray scale pixels were assigned as false or value "0". Therefore, areas containing the color hues in the image were separate from the black and white background. Most of the image processing performed was based on Boolean morphologic operations on these binary images (Lang *et al.*, 1996).

The centroid of left ventricular diastolic cavity, representing the average coordinates for all points composing this cavity was mathematically calculated as previously reported (Lang *et al.*, 1996). This centroid can be described by:

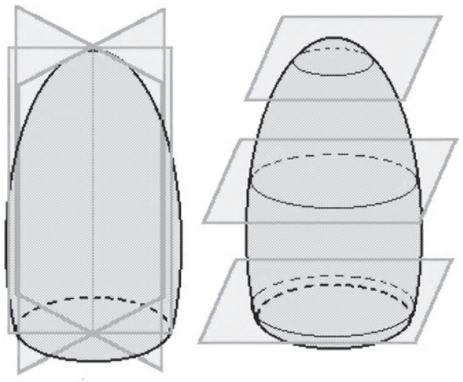

Figure 1. Long axis (LAX) and short axis (SAX) echocardiographic imaging planes for left ventricular cavity. At short axis views imaging was performed at basal, medium and apical portions of left ventricle.

$$\overline{x}_{1,2} = \frac{\iint_s x_{1,2}\, dx_1 dx_2}{\iint_s dx_1 dx_2} \qquad (1)$$

where s is the area of the left ventricular chamber at the end systole, and x_1 and x_2 are the two-dimensional space coordinates.

In the short axis plane processing, the ventricular segmentation was started by connecting the centroid point to a point, manually identified, representing the junction between the right ventricular posterior wall endocardium and the interventricular septum. From this line, the left ventricle was automatically divided into six 60º segments for basal and medium regions and four 90º segments for the apical region (Figure 3).

For the long axis image, a distal point located at the most distant color pixel from centroid was identified. After this, two other points were manually marked in the image, identifying the external limits of the mitral valve ring. These two points were important to exclude the color overlay reflecting the mitral valve excursion from the calculations of left ventricular systolic function. Ventricular segmentation considered the distal point located at apical region and the two points at mitral valve ring. All these points were connected to the centroid and the ventricular chamber was divided into 6 segments with equivalent angles (Figure 4).

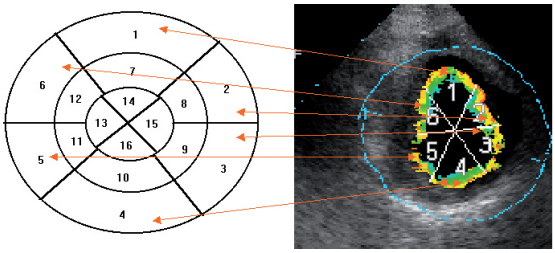

Figure 2. Left ventricular segments in color kinesis image, at basal short axis view, with the correspondent location at polar map display.

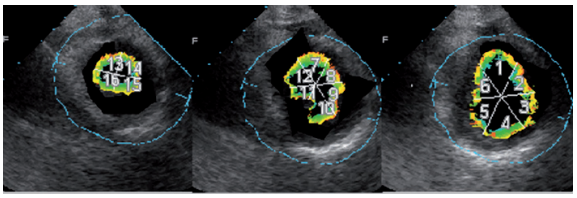

Figure 3. Segmentation on short axis view, respectively, from right to left, at basal, medium and apical portions of left ventricle.

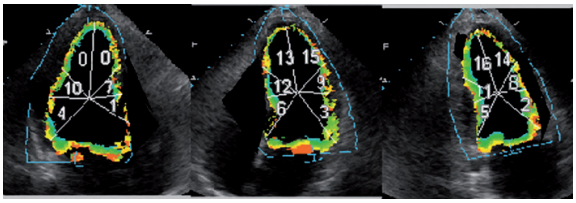

Figure 4. Segmentation on long axis view, respectively, from right to left, at apical two and four chamber, and longitudinal apical views. On longitudinal apical view, apical segments were not considered for quantification (identified as 0 on figure) because this region was divided in only four segments. Note that the angles between segments 4-1, 6-3 and 5-2 are manually selected as starting points for segmentation process.

For each segment, the fractional area change was then calculated as follows:

$$FAC = \frac{A_d - A_s}{A_d} \qquad (2)$$

where A_d is the total area of the segment at the end diastole (corresponding to the total pixel count, including all color pixels and those identified as blood), and A_s is the total area of the segment at the end systole (corresponding to color pixels area).

Semi-quantitative analysis of segmental wall motion

To compare with the results of the automated detection of regional wall motion abnormalities, two experienced observers analyzed left ventricular wall motion from two-dimensional images in normal subjects and patients using the following score: 1-normal; 2-mild hypokinesia; 3-moderate hypokinesia; 4-severe hypokinesia; 5-akinesia and 6-dyskinesia. When a discordant analysis between the two observers occurred, the wall motion score was defined by consensus reached by both observers.

Results

Color kinesis images with adequate quality of segmental wall motion evaluation in normal subjects were obtained in 21 out 23 volunteers (91%). A "bulls-eye" representation of segmental wall motion documented in a normal subject, in short axis views, is shown in Figure 5, while Figure 6 shows the polar representation for the long axis views in a patient studied. Mean values (± standard deviation) of fractional area shortening in normal subjects obtained in short and long axis views are represented in Figure 7. These data have shown a distribution consistent with normality as documented by the Kolmogorov-Smirnov test. Fractional area shortening values were larger and more homogeneous in paraesternal short axis than in apical views, for each segment. In apical views, lower values of fractional area shortening were observed in apical segments as a result, at least in part, of the relative larger size of this region on the segmentation accomplished by the image-processing tool. This limitation did not occur on the short axis view. In addition, reduced values of fractional area shortening documented in apical segments could be related to inadequate tracking of endocardial borders in apical views.

Another relevant aspect of the quantitative analysis of the segmental wall motion, as documented by color kinesis technique, concerns to the large dispersion of fractional area change values observed in the normal group: standard deviations documented in this population were relatively high when compared to the mean values obtained, as we can see in Figure 7.

In this investigation, we considered, in patients with left ventricular dysfunction as evaluated by two-dimensional echocardiography, as proposed by Lang *et al.* (1996), the mean value of fractional area shortening minus one standard deviation as the lower limit

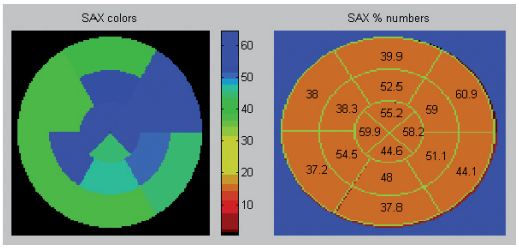

Figure 5. "Bulls-eye" representation of regional fractional area change (FAC) at the short axis views, of a normal subject. FAC values are shown numerically (right panel) and by a quantitative color display (left panel).

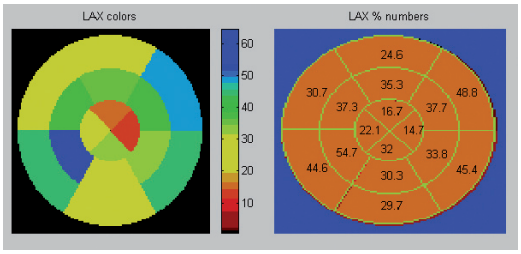

Figure 6. "Bulls-eye" representation of regional fractional area change (FAC) at the long axis views, of a patient presenting left ventricular systolic dysfunction. FAC values are shown numerically (right panel) and by a quantitative color display (left panel).

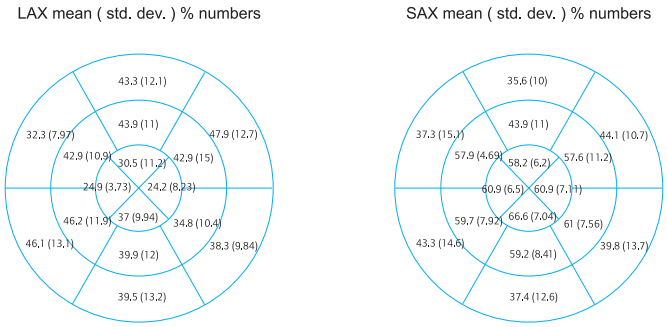

Figure 7. Mean values (± standard deviation) for fractional area change in normal volunteers studied for short (right panel) and long axis (left panel) views.

of normal for regional wall motion, in each of 16 left ventricular segments. Each individual value of fractional area shortening was automatically identified as normal or abnormal considering this definition. Then, these values were compared, segment-by-segment, with the semi-quantitative consensual evaluation of experienced observers. From the total of 336 evaluated segments, concordance between automated grading of ventricular function performed by the imaging processing tool and expert quantification of wall motion was only 63.8% in long axis views and 70.8% in short axis plane. When we considered, in this comparative analysis, only the segments located at papillary level, in the short axis view, the same segments evaluated by Lang *et al.* (1996), this agreement increased to 80.8%. When only the apical four-chamber plane was considered, the agreement between the two techniques was 75.3%.

Discussion

The image-processing tool developed in this study was based on end-systolic color kinesis images, which provide complete spatial and temporal information regarding systolic endocardial excursion in a same image. Quantitative representation of segmental left ventricular motion by polar maps using color kinesis images has been shown feasible, in addition to provide simultaneous quantification of global and regional systolic ventricular function, using a 16 segment model. Previous studies (Koch *et al.*, 1999; Lang *et al.*, 1996; Prater, 1997) have used only the papillary level of left ventricular short axis view and the four chamber view, evaluating, in each plane, only 6 segments, while in the representation proposed in the current investigation, each polar map includes all 16 segments as standardized by the American Society of Echocardiography. Therefore, the proposed "bulls-eye" representation of segmental wall motion allows a simple and direct anatomic association with coronary artery distribution, as well as a more extensive and global quantitative documentation of systolic left ventricular function. From the clinical point of view, this approach could be considered as an advantage considering that cardiologists are already familiar with "bulls-eye" maps that are often used for representing myocardial perfusion during nuclear medicine studies.

The computational procedures necessary to complete each study can be accomplished in a relatively short time, of approximately 15 min, starting from the image acquisition. In addition, it is important to mention that color kinesis images of enough quality for segmental wall motion evaluation were obtained for 91% of the normal volunteers evaluated.

The fractional area shortening documented in the normal group evaluated have shown a more homogeneous distribution in the left ventricular segments of short axis views as compared to those observed in the long axis plane. The magnitude of fractional area shortening was larger in the short axis views than in long axis views. Comparing the apical segments documented in long axis views to the medium and basal segments, it was possible to verify a smaller fractional area shortening in apical region. This observation is probably related to the relatively larger size of the apical segments determined by the segmentation method used or to poor tracking of endocardial borders in this view.

The ability of the image-processing tool described in this study for providing automated detection of wall motion abnormality, as compared to expert semi-quantitative evaluation of left ventricular function, was not quite good. Considering the lower limit of normal as the mean value of fractional area shortening in any specific segment minus one standard deviation, as previously suggested (Lang *et al.*, 1996), for the 336 evaluated segments, agreement between automated grading of ventricular function performed by imaging processing tool and expert quantification of wall

motion was only 63.8% in long axis views and 70.8% in short axis plane. When only the segments located at papillary muscle level, in the short axis view were considered, the agreement between the automated and expert evaluation increased to 80.8%. When only the apical four-chamber plane was considered, the agreement between the two techniques was 75.3%. Therefore, when the same segments were considered the results of the current investigation and those reported by Lang *et al.* (1996) were similar. Probably, this limited ability for automated detection of wall motion abnormality is related to the larger degree of dispersion of the values of fractional regional area shortening, verified in the normal individuals. It is possible that technological development already in progress, allowing, at the same time, improvement in image spatial resolution and larger frame rates (temporal resolution) during color kinesis will reduce that dispersion and enhance the capacity of discrimination by this method.

In conclusion, the proposed "bulls-eye" representation of CK images is quite feasible in a large proportion of subjects and can provide quantitative, semi-automated, segmental and global evaluation of LVWM. However, this image-processing tool has shown a relatively reduced capability for providing automated quantitative identification of left ventricular dysfunction when compared to experienced observers' semi-quantitative wall motion analysis. This limited ability is probably related to the larger degree of dispersion of the values of fractional regional area shortening, verified in the normal individuals.

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