COMPUTER ANALYSIS TECHNIQUES FOR THE TEMPORAL EVALUATION OF CARDIAC WALL MOTION.

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ABSTRACT

Digital image processing is emerging as an increasingly important modality in the evolution of different types of image acquisition and analysis in cardiology. It has become an integral element in the technologies that are being developped and explored. New mathematical concepts in the assessement of cardiac function have been applied to digital images of the heart. Among them, the measurement of temporal changes in regional wall motion of the heart using Fourier analysis led to a significant improvement in the detection of regional alterations in ventricular function. Several imaging modalities can benefit from this approach for the assessement of the temporal sequence of cardiac wall motion.

RÉSUMÉ

Le traitement numérisé des images par ordinateur est une approche qui occupe une place de plus en plus croissante dans les differents types d'investigations par l'image en cardiologie. L'équipement nécessaire pour l'aquisition et le traitement d'images numérisées fait déjà partie intégrante de nombreux appareils utilisés pour le diagnostic en cardiologie. Aussi de nouvelles approches d'analyse de la fonction cardiaque tel que l'évaluation de la synchronicité de mouvement des différentes parties du coeur, peuvent être appliquées à ces images. Une technique d'analyse basée sur la décomposition du mouvement par transformation de Fourier permet d'améliorer la détection d'anomalies segmentaires du mouvement des parois ventriculaires.

KEYWORDS: Digital imaging - Fourier transform- Cardiac wall motion.

With the recent developpement of digital imaging techniques, dynamic images of the heart motion have become accessible to computer processing and analysis. Several cardiac imaging modalities benefit nowdays from digital recording, particularly the radionuclide angiograms, the contrast cine-angiograms and the echocardiograms. All these images can be converted in digital form and processed by computer analysis programs. Such programs not only allow the extraction of morphological information about the heart structures but also permit a quantitative evaluation of the motion of the different regions of the heart. Digital image processing hardware components are largely similar among different systems. Software can also be broken down into separate algorithms that are image independent. The same methods can be applied to images irrespective of their source (isotope, ultrasoud, radiographic). Before the developpment of computer analysis techniques, the evaluation of dynamic images of the heart could only be done visually by a higly trained cardiologist. A significant improvement in diagnostic accuracy when using dynamic analysis techniques for the evaluation of the heart motion has been well demonstrated. Recent analysis techniques relying on a temporal evaluation of the heart wall motion are significantly more sensitive in detecting cardiac abnormalities than conventional global morphological parameters. Computer techniques offer a more objective and reproducible evaluation. The heart wall motion being a complexe mechanism, conceptual models and mathematical algorithms are needed to adequately analyze the temporal sequence of changes occuring during the heart cycle. We have particularely studied the application of Fourier transformation methods for the evaluation of segmental cardiac motion. The Fourier transform concept is based on the hypothesis that any periodic function can be represented as the sum of cosine and sine waves of different frequencies, each frequency characterized by a specific amplitude and phase. Expressed alternatively, Fourier analysis describes a signal in terms of its frequency content. Because cardiac contraction is generally a regular, reccurent event, it has periodicity and is well suited for the use of temporal Fourier analysis. The displacement of a point within the ventricle through the heart cycle can roughly be approximated with one cosine wave at the fundamental frequency, the heart rate. This cosine wave at the fundamental frequency is referred as the first Fourier harmonic. The first harmonic amplitude is an estimate of the total extent of motion. The phase shift of the first harmonic is a reasonably good approximation of the timing of the oscillation and can be used as a parameter to measure delays in wall motion between different regions of the heart. The changes in the first harmonic phase however does not differentiate between delays in the filling and in the emptying phase of the heart cycle. Higher order harmonics provide more information about the motion profile in the different parts of the cycle but they are more sensitive to artefacts and noise interferences related to each imaging technique (1). The assessement of regional abnormalities in the temporal sequence of wall motion is of great interest for the clinical evaluation of heart diseases. It allows the detection of subtle changes of cardiac function in several types of cardiac disease before any changes in the global cardiac performance could be identified. Computer processing of digitized images not only allows functional parameters to be extracted from a sequence of images but also offers the possibility of displaying the resulting distribution on parametric or functional images representing a topographic map of the changes of the measured parameter in each point of the image. In fact, the advantage of parametric imaging is to enable the eye to easely dectect regional changes in dynamics that are otherwise not readily apparent on visual inspection of the original data.

Temporal Fourier analysis of cardiac motion applied to different imaging modalities:

(1) Radionuclide angiogram was the first imaging modality to benefit from computer processing due to the fact that the dynamic recording of sequential isotopic images of the moving heart could only be performed by computer recording triggered by the electrocardiographic (ECG) signal. Images of the heart cavities obtained after labeling the red blood cells with radioactive Tc-99m are obtained by a gamma scintillation camera connected to a computer. The average time interval of the cardiac cycle obtained fron the ECG is divided by the computer into a fixed number of subintervals. The information acquired from each subinterval of the cardiac cycle is then stored into separate frame in the computer memory. The process is then repeated usually for several

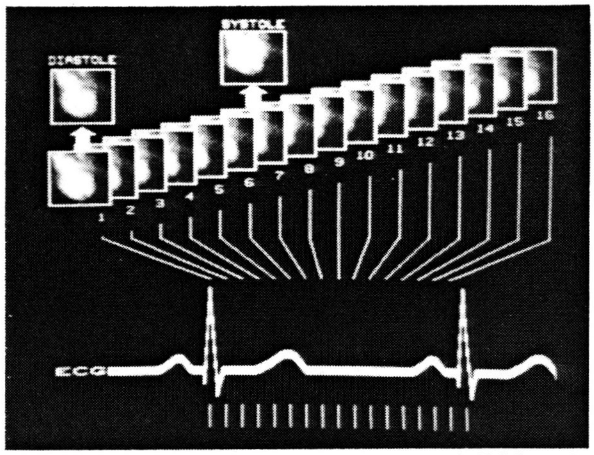

Fig 1 : *Recording of a sequence of ECG gated radionuclide angiographic images. The average heart cycle period is divided into 16 intervals and acquisition starts at the begining of each cycle. Successive cycles are added during 3 to 5 minutes in order to obtain an average cycle with satisfactory target to background count ratio.*

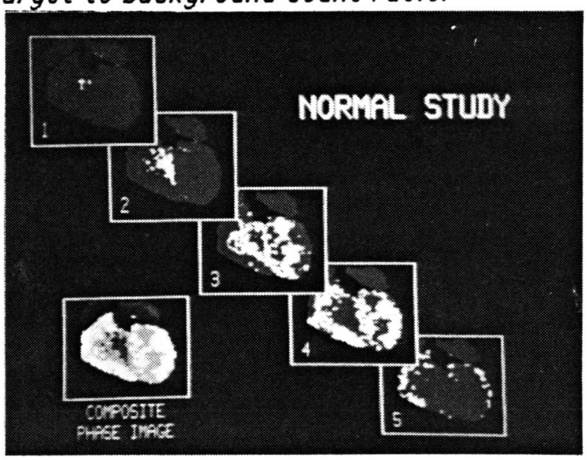

Fig 2 : *Successive parametric images showing the temporal sequence of normal regional ventricular wall motion recorded by radionuclide angiography. Motion starts close to the septal area between right and left vetricle and spreads symetrically towards the two ventricles. A composit phase image in the lower left corner shows in shades of gray the same temporal sequence of wall motion; bright regions being regions wich move later during the cardiac cycle than the dark regions.*

hundred cardiac cycles, until sufficiently high count densities per image frame are obtained. The data are then formulated in a multiple frame mode and displayed in a closed loop movie form providing a visual assessment of the chamber dimensions and wall motion. The counts present in any point of a given frame, after background substraction are proportional to the volume contained in that ponctual region of the heart chambers. For each pixel in the images a time activity curve can be extracted and Fourier analysis is applied to calculate the phase and amplitude of the first harmonic. These two parameters being calculated in each point are then displayed in color coded parametric images showing the topographic distribution of the temporal sequence (phase) and amplitude of wall motion of the different parts of the heart (2).

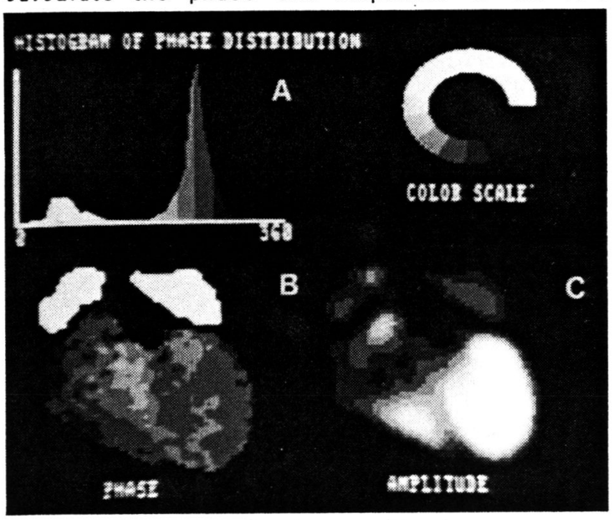

Fig 3 : *Phase analysis results from a normal patient: (A) Histogram of phase distribution, (B) Phase image, (C) Amplitude image. The phase image shows the topographic distribution of temporal sequence of wall motion in each picture element. Areas with early phase are in bright and areas moving last are in dark gray. The histogram of phase distribution shows two peaks; an initial small peak corresponding to the atrial phases and a second sharp peak corresponding to the ventricular phases. The histogram is colored using the same color scale as for the phase image in order to easely identify areas on the phase image corresponding to the different segments of the histogram. The narrow ventricular peak in this example indicates a normal synchronous ventricular wall motion. The amplitude image depicts the amplitude of count changes in each picture element.*

Many clinical studies performed in our institution and in many other centers have well demonstrated the usefulness of this new quantitative approach for the evaluation of cardiac wall motion abnormalities. This technique depicts not only delays due to electrical conduction abnormalities but also regional asynchrony due to mechanical disturbances. In coronary artery disease for example this method was found to be more sensitive than conventional criteria for the detection of ischemia induced abnormalities during exercise (3).

(2) X ray cineangiograms consist of radiological images recorded on film after injection of radioopaque contrast medium into the blood ciculation to visualize the different chambers of the heart. The recent developpement of digital imaging techniques offers an alternative to film as the primary recording medium for radiography, and digital image processing methods can be applied. This type of images has a much better spatial resolution than radionuclide angiograms but due to inhomogeneity of dilution of the contrast medium with the blood, changes in image density in each point of the cardiac cavities is not always directly proportional to changes in blood volume. Such inhomogeneity is particularly evident in images obtained by conventional injection of contrast medium directly into the heart cavities. With digital image enhancement methods it is however possible to obtain satisfactory images of the heart cavities by intravenous injection of contrast medium. In this case the contrast material is more homogenousely mixed to the blood when it reaches the heart and changes in image density is directly related to changes in blood volume. To avoid the artefacts due to inhomogeneity of contrast medium dilution we have developped and applied a Fourier analysis technique of ventricular wall motion based on a radial evaluation of the ventricular wall displacement along 180 radii drawn from the center of mass of the ventricle over 360 degrees (4). This technique can therefore be applied to images obtained either by conventional intraventricular injection or by intravenous injection of contrast medium. Quantitative information about the timing of motion of the different segments of the ventricle are computed and displayed on parametric color coded images. Functional parameters can be extracted from the parametric images in order to assess quantitatively heart function and dynamics.

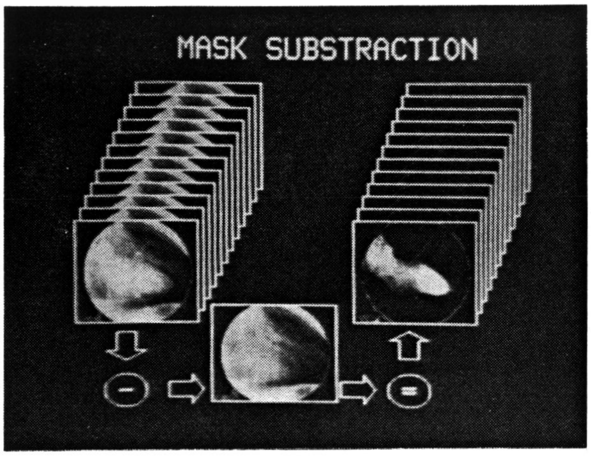

Fig 4 : *Mask substraction technique applied to digitized cineangiographic images obtained by intravenous injection of contrast medium: A single mask image obtained prior to the injection of the contrast medium is substracted from successive images representative of a single heart cycle.*

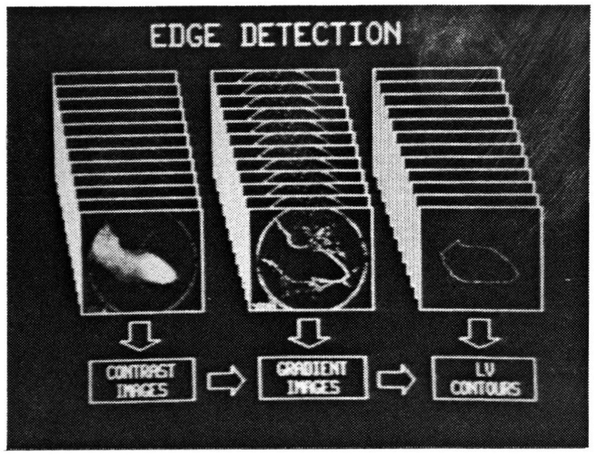

Fig 5 : *Image processing of substracted images: after edge enhancement using spacial gradient transformation, ventricular contours are obtained on the sequence of digitized images.*

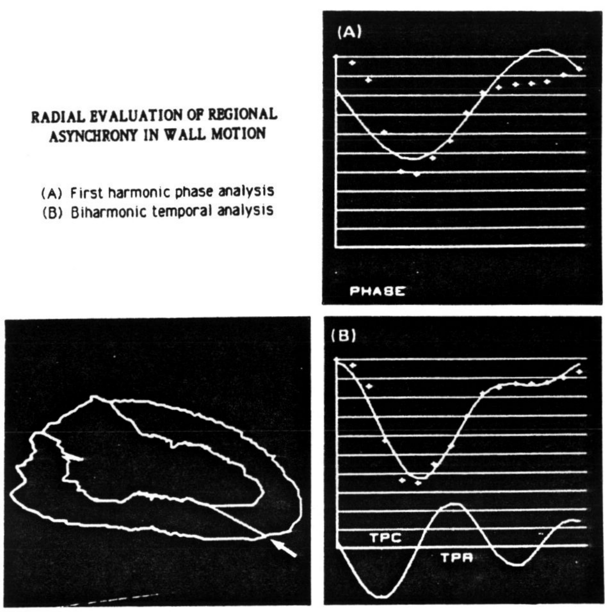

Fig 6 : *Fourier analysis of ventricular wall motion along one single radius (arrow).*
A)*- First harmonic of the Fourier transform (solid curve) of a selected radial motion curve (dotted curve). This sinusoidal curve gives a simple approximation of the timing of motion but does not differentiate between contraction and relaxation.*
B)*- The solid curve is obtained from the two first harmonics the Fourier transformation of the same segmental motion curve (dots). The first derivative of this curve is also plotted and represents the rate of changes in length. The maximum rate of emptying and maximum rate of filling are depicted and referred to as TPC and TPR standing for time of peak contraction and time of peak relaxation.*

Furthermore, the promise of functional or parametric imaging is to enable the eye to dectect subtle changes in dynamics that are otherwise not readily apparent on inspection of the original data.

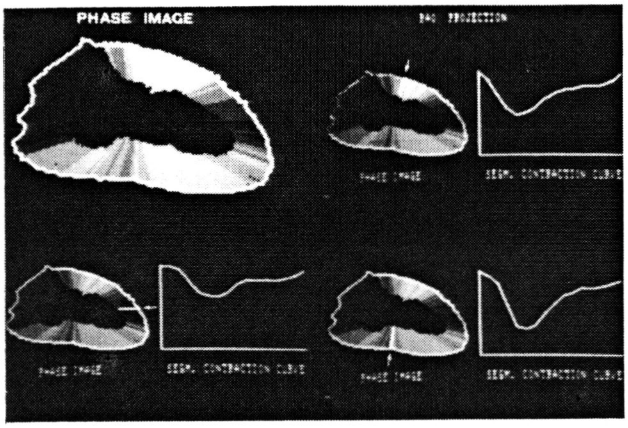

Fig 7 : *Prametric phase image obtained by Fourier analysis of digitized cineangiogram in a subject with normal ventricular wall motion. The temporal sequence of wall motion is displayed in a predefined color scale. Bright areas are segments which move first while darker regions move later during the cardiac cycle. Radial motion curves of three selected segments (arrows) are displayed.*

(3) Ultrasound two dimensional echocardiogram with its comprehensive display of left ventricular cavity, size, shape, and wall motion was a logical candidate for the application of computer techniques. Some difficulties and limitations surrounding computer interpretation of ultrasound data must however be considered. The mechanism underlying image degradation must be clearly understood before algorithms can be developped to reverse them. Grayscale manipulation, smoothing, and integration of information from several heart beats are methods which have been borrowed from other imaging systems and applied to echocardiographic images. Two distinct problems exist with this technique: the location of a pictorial boundary on the image, and the determination of the relation of this pictorial boundary to an anatomic one. Early techniques required the manual outlining by an operator of cardiac chamber surfaces for subsequent computer measurement, but more recent method employ automated methods of boundary recognition which are more or less reliable depending on the underlying image quality and image acquisition performance. However when cardiac chambers are easely outlined, a Fourier analysis technique of ventricular wall motion can be applied offering the same advantages described for angiographic images.

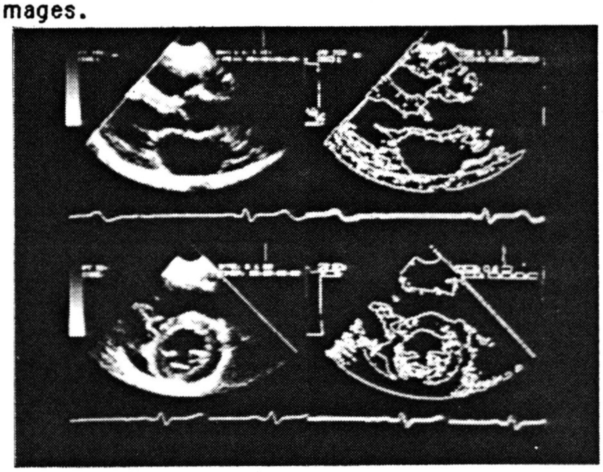

Fig 8 : *Ultrasound echographic images of the heart before (left) and after (right) edge enhancement using a gradiant transformation.*

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